TEACHING SCIENCE IN SCHOOLS

TEACHING SCIENCE IN SCHOOLS

BY

JOHN BROWN, M.A., B.Sc.

FORMERLY ASSISTANT TO THE PROFESSOR OF NATURAL PHILOSOPHY IN THE UNIVERSITY OF GLASGOW, HOULDSWORTH RESEARCH SCHOLAR, AND INSPECTOR OF SCHOOLS UNDER THE LONDON COUNTY COUNCIL

UNIVERSITY OF LONDON PRESS, Ltd.

WARWICK SQUARE, LONDON, E.C.4

First Printed 1925
Second Edition 1930
Reprinted 1936
Third Edition 1943
Reprinted 1949

AGENTS OVERSEAS

AUSTRALIA, NEW ZEALAND AND
SOUTH SEA ISLANDS
W. S. Smart, P.O. Box 120, Sydney, N.S.W.
Showroom: 558, George Street.

CANADA
Clarke, Irwin & Co., Ltd.,
480-486, University Avenue, Toronto.

EGYPT AND SUDAN
Dino Judah Nahum P.O. Box 940, Cairo.
Showroom: 44, Sharia Sherif Pasha.

FAR EAST
(*including China and Japan*)
Donald Moore 22, Orchard Road, Singapore.

INDIA
Orient Longmans Ltd.,
Bombay: Nicol Road, Ballard Estate.
Calcutta: 17, Chittaranjan Ave.
Madras: 36a, Mount Road.

SOUTH AFRICA
H. B. Timmins P.O. Box 94, Cape Town
Showroom: 58-60, Long Street.

Printed & Bound in England for the University of London Press, Ltd.,
by Hazell, Watson & Viney, Ltd., Aylesbury and London

PREFACE

This little book owes its origin to certain lectures I have given to teachers in the course of the last five years. It has been my privilege during these years to visit many schools, to observe, among other things, what is being attempted and accomplished in the course of the science lessons, and to discuss with head and assistant teachers, individually and collectively, the teaching of science.

The book is accordingly one for the teacher and for the training college student. It is not a text-book; the teacher and student will find an ample supply of these already on the market. It is intended to help the teacher, particularly the elementary school teacher, in the choice of subject-matter for the science curriculum, and to indicate to him the lines he might follow in his teaching, whether he possesses special accommodation for practical experimental work or not. Subjects suitable for girls as

well as for boys are discussed. If the book proves of assistance to teachers in their important work I shall be satisfied.

My experience in the schools has convinced me that a book of this nature is required. It is true that there was issued some years ago an admirable Report on the position of Natural Science in the educational system of Great Britain, but departmental reports are apt to be read with approval at the time they appear and to be soon forgotten. The Board of Education recognise the need for the issue on their part of suggestions on the teaching of science, for in the Board's Report for the year 1923–24, dated June 22, 1925, it is stated, *in referring to the issue of Memoranda* of Suggestions dealing with the teaching of particular subjects, that " science is, indeed, the only important branch of the curriculum not hitherto so dealt with."

It is inevitable in a book of this nature that certain of the topics discussed and certain of the views expressed will have been considered by other writers, but for the sake of completeness it is desirable they should be repeated here. I have to acknow-

ledge gratefully help from many sources—in particular, the report on "Natural Science in Education" mentioned above. I have also had the benefit of the exchange of views with certain colleagues and others interested in the subject. I am specially grateful to Professor T. Percy Nunn, who has read the book in proof and has offered helpful suggestions. Finally, I wish to express my indebtedness to my friend, Dr. P. B. Ballard, for his valuable criticism of the text and for his kindly help in reading the proofs.

As an officer of the London County Council, I am obliged to state that the Council accepts no responsibility for any of the views expressed in this book.

J. Brown.

August 1925.

PREFACE TO THE SECOND EDITION

SINCE this book was written there has been issued, at the end of 1926, a report by the Consultative Committee of the Board of Education entitled, "The Education of the Adolescent" (commonly called "The Hadow Report"), which has already greatly affected the trend of national education in England. This report recommends, among other things, a "fresh start" for *all* pupils at the age of eleven plus, a policy which has been officially endorsed by the Board of Education, with the result that local education authorities throughout England are to-day busy reorganising their elementary schools so that pupils who do not proceed at the age of eleven plus to secondary or to selective central schools, will be gathered together into "senior" schools (or classes) specially suitable for dealing with children between the ages of eleven plus and fourteen to fifteen plus.

This reorganisation of elementary schools into "junior" and "senior" schools, with the transfer (or "break") at the age of eleven plus, necessitates a revision of the aim and the curriculum of each type of school, and science of some kind will rightly have a place in the time-table of both schools. Fortunately, the courses suggested in this book (Chapter VII *et seq.*) had originally been framed on the basis of a "break" at the age of eleven to twelve; no alteration is therefore needed to make the text conform to the new system of national education. I hope teachers in the new "junior" and "senior" schools will find the book helpful.

In this edition I have taken the opportunity to bring up to date the list of books suitable for the science library given in the Appendix, by adding the names of certain books which have appeared since the printing of the first edition in 1925.

J. B.

March 1930.

PREFACE TO NEW IMPRESSION

On 1st April, 1945, the English system of popular education was remodelled in accordance with the new Education Act, 1944; and on 1st April, 1947, the minimum age at which pupils can leave school was raised from fourteen to fifteen years. Under the new Act, the public system of education ceased to be organised in the two self-contained compartments of " elementary " and " secondary " schools, and became one continuous process organised in two main stages: (i) " primary " up to the age of eleven or twelve, and (ii) " secondary " thereafter up to the age of fifteen or more. The word " elementary " has now disappeared from the system, and the English system of state education is now similar to that of Scotland, with provision for some form of " secondary " education for *all* pupils from the age of eleven or twelve onwards to eighteen or nineteen if desired.

These changes, however, need not affect the

significance of the views expressed in this book. Fortunately, throughout the original text ages for the various stages are given, and these still correspond with the new set-up. The reader, therefore, should have no difficulty in following the views expressed, or the treatment or courses suggested for pupils in different types of schools, as the ages given indicate clearly the pupils for whom these are suitable.

Moreover, the main thesis of the book is still as relevant and as important as ever—namely, the need for broadening and humanising the teaching of science for the large majority of the pupils in our schools, to show the relation of science to everyday life and to give the subject a wider, more general and more lasting appeal.

J. B.

1948.

CONTENTS

TEACHING SCIENCE IN SCHOOLS

CHAPTER I

WHY DO WE TEACH SCIENCE?

SCIENCE has now established its claim to a place in the school curriculum. Practically every school, whether secondary or elementary, attempts to give its pupils some instruction in the subject. The instruction given may be bad, or it may be very meagre, but the wish to provide the instruction exists, and there are few people nowadays who require much convincing on the question of the wisdom of the inclusion of science in the school curriculum.

It has taken a good many years of active and persistent effort to reach this position of having the claims of science recognised, and one may enquire, What has brought about this victory? Various reasons for it

can be adduced, most of which have a certain amount of truth in them. Some maintain that science is taught because it makes people careful and systematic, and that these desirable habits, acquired as the result of accurate measurement, will be "carried over" into one's general character and manner of living; others maintain that science is taught in order to provide a training in, and knowledge of, what is called "scientific method" so that one may, in later years, apply this method in the treatment of the general problems of life; others would have science taught because it is of great practical value, and, in support of this, they point to the part science has played in the growth of civilisation, to what the scientific services achieved in the late Great War, and to what they are likely to be required to do in future wars. Much might be written on this subject, but, it seems to me, the reasons for the inclusion of science in the school curriculum are exactly the same as those for the inclusion of English, of history, of geography, of Latin, of French, or of any other subject now generally taught in our schools. These

subjects are taught because they provide a liberal education; they are part of the equipment and preparation for life which we expect the school to give to its pupils so that they may play their part in the community as intelligent citizens, able to give efficient service, to appreciate and enjoy the beauty and the wonder of the world in which they live, and to take delight in the wealth of culture in its many forms left to them by past generations and civilisations. I wish to make no special claims for the teaching of science to the exclusion of other subjects now generally taught. It takes its place side by side with them as an essential element in one's education; it affords a knowledge of certain facts and laws and an insight into methods and data peculiar to the domain of science which should be provided for every pupil on an equal footing with the other subjects in the curriculum.

Most school subjects have a direct utilitarian value, and so has science. Its peculiar utilitarian value need not be elaborated here. It will be sufficient to mention that we live to-day in a world of scientific achievement; we have daily flying services between this

country and the Continent (an aviator in a small machine has just flown from London to Zurich and back to London in the same day); we converse and carry on business daily by telephone; wireless receiving apparatus is to be found in daily use in millions of homes; we light our houses, streets, and shops, and drive machinery, trains, and tramcars by electricity; the internal combustion engine has filled our roads with motor transport; we have magnificent and powerful steam locomotives and ocean liners, and daily we hear of new triumphs and miracles in medical and surgical science.

Science, in common with other subjects, gives one a more intelligent and appreciative outlook upon life. Its facts and problems are not the same as those of English or history or the classics, but they are none the less important in our equipment for the future. In our daily lives we see and hear of natural phenomena and continually meet and use the applications of science in the service of man, so that some knowledge of these should give more interest and appreciation to life generally.

Science, too, like every other school sub-

ject, has a cultural value, even if we use the term "culture" in its narrowest sense. It has a literature of its own and may make an appeal as powerful and as elevating as that of the more humanistic studies. Unfortunately, this side of science teaching has been badly neglected in the past, and little attempt has been made to introduce pupils to the more important historical, romantic, and biographical incidents in general science. Much inspiration can be obtained from a knowledge of the work of great science pioneers like *Galileo*, *Newton*, *Watt*, *Faraday*, Darwin, Pasteur, Kelvin, and Edison.

Lastly, much has been claimed for the teaching of science because of the training it affords in "scientific method." Valuable as a knowledge of scientific method is, I do not wish here to emphasise this aspect of science teaching, for I am convinced that the attempt to teach science because of the training it may afford in this respect has been the cause of much bad science teaching in the past and even to-day. The tendency has been to emphasise those branches and parts of the subject which lend themselves specially well for this

purpose and to ignore completely important branches of the subject because they are not so suitable. Moreover, it is very doubtful if all that is claimed for the scientific method can be achieved. Personally, I do not believe it can, except in a very few cases. A long course, including university study, may accomplish something of it, but the very large majority of pupils in secondary schools acquire little of it, and it is certainly beyond the possibility of pupils in elementary and central schools. I wish, therefore, to make no plea for the teaching of science in schools simply on the grounds of its training in "scientific method."

CHAPTER II

THE PRESENT POSITION AND THE IDEAL AIM

ACCEPTING the position that science has won a permanent position in the curriculum of our schools, both elementary and secondary, let us now consider the question of what is actually done in the way of science teaching. A certain amount of science instruction is given in our elementary schools, in preparatory schools, and, in an increasing amount, in our secondary schools, technical schools, colleges, and universities. But when we examine the courses of instruction given and know what work is done and the nature of the teaching in these different institutions, we are soon forced to the conclusion that all is not well with our science teaching. We find boys in elementary schools studying physics, for example, and attempting experimental work which we find boys at a later age in secondary schools also attempting;

and again at a still more mature age students in colleges and universities may be found attempting the same type of experimental work. There is obviously something wrong—some lack of co-ordination—when such a state of affairs as this exists. Each type of institution seems to take it for granted that a fresh start is necessary, and thus the university student, in common with the school pupil, commences with exercises in weighing and measuring, determines densities by a wonderful variety of methods, proceeds to the action of heat on solids, liquids, and gases, determines specific heats of certain substances, latent heats, etc. The fault lies, I think, mainly with the junior schools, and is probably due to the fact that many of the teachers in our elementary and preparatory schools and in the lower forms of our secondary schools, when given the opportunity to teach science to their pupils, have no knowledge of science except what they acquired from some course in bygone days which they were fortunate (or unfortunate) enough to receive in a secondary school or training college, or even in a university, and they proceed forthwith

to put their pupils through a similar course with perhaps some slight simplification. These teachers fail to realise that the course of science instruction they received ten, twenty, or thirty years ago is not necessarily the best course for pupils in our schools to-day. And thus we find that while certain other subjects, such as geography, physical education, and English, are being taught to-day on new and more rational lines than formerly, and the spirit of this new teaching in these subjects is steadily spreading, the same changes are not evident in the teaching of science.

The need of drastic change in the nature and subject-matter of the science taught in many of our schools, and some indication of how matters may be improved, will be obvious if we keep clearly in mind the reasons for giving the subject a place in the curriculum. We teach science in our schools mainly because a general education is not complete if it does not include some acquaintance with natural phenomena, the physical laws and properties of matter, and the applications of scientific principles met with in our everyday life. We must not,

therefore, teach science as if each and every one of our pupils will become scientists, or will pursue careers in which an expert knowledge of some branch or branches of science will be essential. We have to remember that by far the greatest proportion (over 90 per cent.) of the pupils of compulsory school age under instruction in our schools will finish their education, as far as school is concerned, soon after they reach the age of fourteen, and will thereafter receive little or no definite instruction at the hands of a teacher. We have also to remember that even of those who are fortunate enough to proceed from the elementary or preparatory school to higher education in a secondary school or elsewhere only a very small percentage will proceed to universities to continue their study of science or will enter employment in which a technical knowledge of certain fields of science is of direct value.

Thus we are driven to the conclusion that the science course to be taught in our schools should not be that which is suitable for the future expert science specialist, and which can be of value to only the small

minority of pupils, but rather a good general science course on broad humanistic lines which will be of value to all our pupils as a part of a sound liberal education.

Numerous attempts have been made to give, in a clear and brief statement, the objective of good science teaching, and different writers at different times have stressed the importance of different aspects of the teaching. Perhaps the statement which most clearly and comprehensively gives this aim is that which is found in the report of the Committee appointed in 1916 by Mr. Asquith (then Prime Minister), with Professor Sir J. J. Thomson as chairman, to enquire into the position of Natural Science in the educational system of Great Britain. According to this report the teacher of science should aim at two main objectives:

(1) To get his pupils to reason about things they have observed, and to develop their powers of weighing and interpreting evidence.

(2) To acquaint his pupils with the broad outlines of great scientific principles, and with the ways in which these are exemplified

in familiar phenomena and applied in the service of man.

This is an admirable statement, and one which should serve teachers of pupils and students of all ages and in all types of schools and colleges. If teachers, in framing their science course and in their daily teaching, keep before them these two objectives, particularly the second of them, the position and value of science in our schools will rapidly improve.

At the present time the field covered in the usual science courses of our schools is much too restricted ; as a rule, only sciences which lend themselves easily to experimental work under the conditions of a school laboratory are taught, with the result that pupils, and even students, leave schools and colleges at a mature age and after several years of study of science knowing very little of broad general science topics, knowing nothing at all of certain important sciences or branches of science, and possessing little or no love of the subject or knowledge of the more humanistic and inspirational side of it. They may be able to determine accurately the specific gravity of iron by at

least two methods (one of these may even be by means of Nicholson's hydrometer !), or the specific heat of copper, or the coefficient of linear expansion of brass, or the hydrogen-equivalent of zinc ; they may, if they have included electricity in their course of laboratory work, be able to compare the electromotive forces of two cells by several methods, or determine the internal resistance of a battery, but when asked to talk about, even in a general way, the generation of electricity for town-supply, or the running of an electric tram-car or train, or the main principles involved in a steam engine or internal combustion engine, or how a sunken liner can be raised by salvage operations, they are in difficulties. After an advanced course in electricity and magnetism they may be unable to rectify a simple fault in an electric bell or repair a fuse. Others, again, have learned little of the works of eminent scientists ; they have never been thrilled by the romance of science, by the triumphs of modern engineering, chemistry, physics, astronomy, and biology. The history of the subject and the lives of the great pioneers of science are a closed book to them.

All this has been brought about by a loss of perspective, by allowing experimental work to become an end in itself. After passing through the stage of having had too little practical work in our science teaching, we are now in the stage of having too much, and an effort should be made to reach a position of equilibrium in which experimental work by the pupils, demonstration and lecture work by the teacher, and reading and private study by the pupils will all have their legitimate place and proper proportions.

CHAPTER III

SCIENCE TEACHING IN THE PAST

THE difficulty of preserving a proper balance between experimental and theoretical (non-experimental) work is one which has persisted through the ages ever since the beginnings of scientific study based on direct observation and experiment. Further, it is a difficulty which is likely to be ever present with us, for with changing times we have changing opinions.

It is impossible to say exactly when experimental methods in science first began, although most schoolboys know that the principle of Archimedes (287–212 B.C.) was formulated as the direct result of experiment. It is, however, certain that the growth of organised scientific knowledge became rapid and sure only when the value of practical experimental work came to be appreciated. And many ancient beliefs and theories held to be unchallengeable were

completely exploded as soon as the test of experiment was applied. One often wonders why so simple and obvious a test was not applied earlier. Thus, Galileo (1564–1642), by the simple experiment of dropping bodies from the top of the leaning tower of Pisa, demonstrated the equality of the velocity of falling bodies of different weight and thus upset the earlier theoretical teaching that a body, say, four times as heavy as another will fall through a given distance in a quarter of the time taken by the other. And it is remarkable that so deep-seated was the belief in the teaching of Aristotle that even this practical demonstration was not sufficient to convince many of the learned men of Galileo's time. This great pioneer of the modern science of dynamics again came into conflict with the "pure" teaching of Aristotle in the field of astronomy when, in 1610, he directed his telescope to the heavens. It required the long series of observations so patiently and accurately made and recorded by Tycho Brahé (1546–1601) and the telescopic observations of Galileo to break down the wrong astronomical theories supported by Aristotle and those

who followed his teaching ; and these observations of Brahé, passing into the hands of his pupil, Kepler, enabled the latter to formulate his three famous laws of planetary motion upon which Newton (1642–1727) built, and which form the foundation of modern mathematical astronomy.

What observatories did for astronomy, laboratories did for the other sciences. As Roger Bacon, in the thirteenth century, advocated, "*Sine experientia nihil sufficienter sciri potest.*" The early alchemists had laboratories, and from these grew up the science of chemistry ; the astrologer, alchemist, and wizard became respectively astronomer, chemist, and physicist. Samuel Pepys tells us that Charles II had a "little elaboratory" and was interested in anatomy. The King's general interest in science is well known, for it is due to him that Greenwich Observatory was founded in 1675, and he gave to the Royal Society its first charter in 1662. This Society remains the foremost scientific society in this country, and it has included among its members eminent scientists who have achieved fame in their particular fields of labour. The

story is told that King Charles II asked the Society to consider why it was that if a gold-fish is placed gently into a full vessel of water, the water does not overflow. The members carefully considered and debated the problem, and finally offered various explanations of the phenomenon to the King. They must have been surprised when the King informed them that their theories were not correct, for if the gold-fish is put into the full vessel the water *does* overflow. The story, even if untrue, illustrates the value of practical experiment in science.

Turning now to the question of the use of laboratories for the purpose of teaching apart from their use by private individuals interested in experimental work, we find laboratories established first at Oxford and, a few years later, at Cambridge, about the end of the seventeenth century. These were used mainly in connection with the teaching of chemistry, a professorship in chemistry having existed at Oxford since 1683, and at Cambridge since 1702. In 1783 the first professorship in Natural and Experimental Philosophy was established at Cambridge. There is evidence of attempts by

certain pioneers in the seventeenth and eighteenth centuries to introduce the study of experimental natural philosophy into schools. Thus we find a certain Benjamin Worster giving practical instruction in mechanics, hydrostatics, and optics at a fee of two and a half guineas for the course early in the eighteenth century in a school in London. He embodied his teachings in a text-book: "A Compendious and Methodical Account of the Principles of Natural Philosophy: As they are explained and illustrated in the Course of Experiments performed at the Academy in Little Tower Street. By Benjamin Worster, 1722."

Up till quite recent times science gained little hold upon the schools. Attention was called to the neglect of science in the Report of the Royal Commission on the Public Schools in 1864. At this time the head master of one of the greatest schools in England stated that "instruction in physical sciences was, except for those who have a taste and intended to pursue them as amateurs or professionally, practically worthless." But public opinion was meantime being educated in favour of science by writings like Spencer's

"Education" (1861); the achievements and teaching of men of science like Huxley (1825–1895), Darwin (1809–1882), and Kelvin (1824–1907), were attracting public interest, and bit by bit science as a school subject was given a place. Ground was yielded grudgingly, and even where the facilities for teaching the subject were available, the science courses were considered suitable only for the less promising pupils; the more promising pupils were encouraged to study the classics and mathematics as being more worthy and suitable subjects. The controversy between science and the classics as to which provides the better type of education need not be discussed here. It is unfortunate that it is still occasionally revived.

Naturally, such teaching as was then given was more theoretical than practical, for experimental work, involving the provision of a laboratory and apparatus, is costly. Experiments may have been performed by the teacher in the way of demonstrations to illustrate the lessons, but individual experimental work by the pupils such as we know it to-day came later and

only secured its present strong position early in the present century. Of the influences at work for the promotion of science teaching in the schools mention must be made of the British Association, the various associations of science teachers and of head teachers, and the writings and teaching of Professor H. E. Armstrong. Schemes of instruction were prepared which insisted upon experimental work on the part of the pupils. They were to discover everything for themselves and to be told nothing; accurate measurements and quantitative results were the basis of the course. The adoption of this principle by the universities, and by the secondary schools, has fixed upon our educational system the rigid, narrow, and relatively uninteresting teaching of science so common in our schools to-day. Laboratories have been provided in our schools, and many of our teachers have become obsessed with the idea that all science must be taught by individual experiment, that things have to be weighed and measured, that certain physical properties of matter have to be discovered and their numerical values accurately determined. The

consequence has been that in many cases experiments are done merely for the sake of doing them, and those sciences which do not involve measurement and quantitative work have been completely neglected. These teachers have lost sight of the real function and aim of education; and the result is that their course of science is very limited in range, the ground is covered slowly, and the pupils leave school with little or no sense of appreciation of their physical environment, blind to the wonders that surround them, and often ignorant of the movements and constitution of the heavenly bodies; their natural curiosity regarding the "how" and "why" of everything has not been satisfied or stimulated; they know little of nature and her ways, of the development and evolution of plant and animal life; the romance of modern scientific discovery and invention has not been opened up to them, and the humanising influence of the subject has been kept entirely from them.

CHAPTER IV

THE STATEMENT OF THE PROBLEM

In the preceding chapter I have briefly outlined some of the important stages in the growth of the study and teaching of science, and have suggested that in recent years, as far as instruction in many of our universities and schools is concerned, the pendulum has swung from one extreme position, in which too little individual practical work was done, to the opposite extreme, in which so much individual experimental work is forced upon the pupil or student that he finishes the course (or is compelled by the limits of time to discontinue it) knowing little of the larger field of general science. And this is practically the position in which we are to-day. The pendulum, I hope, has reached the end of its swing, and I trust its return swing will be sufficiently "damped" to bring it to a

position of equilibrium in which full and proper recognition will be given to the equally important claims of practical work and of a general knowledge of important scientific principles and achievements in as wide a field as possible. Let us now consider how this position is to be reached and what suggestions can be made to improve the state of science teaching in our schools.

The problem is rendered difficult at the outset by the presence in our education system of so many different types of schools, each with its own function to perform and each differing from the others, even in the same class, in resources and in facilities for giving instruction in this subject. Thus, under a large local education authority like London we find elementary schools, central schools, secondary schools, trade schools, technical institutes, polytechnics, day continuation schools and evening institutes, in each and all of which science teaching of some kind or other usually has a place. In addition to schools of the above types, there are preparatory schools, providing instruction for pupils of elementary school age in preparation for secondary and public schools, and

in these preparatory schools science may or may not form part of the curriculum. As far as day schools are concerned, we may, for our present purposes, group the pupils in the following three classes:

(*a*) Those who leave school at the age of fourteen years: that is, at the close of their period of compulsory attendance at school.

This is the largest group and includes all elementary school children who do not pass on to higher education, though some of them may continue their studies in evening schools.

(*b*) Those who leave school at the age of fifteen or sixteen years.

This group would include children who attended ordinary elementary schools up to the age of about eleven years and then were transferred to central schools for a course lasting about four years, and also children transferred to trade and similar schools at the age of about thirteen years for a two or three years' course of instruction with a definite bias of a vocational nature.

(*c*) Those who leave school at the age of seventeen to eighteen years or more.

This group would include those who have had the advantages of a secondary or public school education or its equivalent.

Some indication of the relative sizes of these groups may be obtained from the statement recently made by the President of the Board of Education that less than 4½ per cent. of all children in grant-aided secondary schools in England go on to a university, and less than 9 per cent. of elementary school children go on to secondary schools.

In group (*a*) a certain amount of science teaching of a simple nature is expected and is usually attempted. The amount and quality of the teaching vary considerably from school to school according to the tastes and views of the head teacher or of individual members of the staff. The amount and type of the instruction given in this group, and to a less degree in the other groups, are also influenced by the facilities provided in the way of special rooms or laboratories and of apparatus and material. In some schools there may be no special provision for practical work; in others there may be nothing more than a gas connection for use

with a Bunsen burner, while in a few more fortunate of the elementary schools there may be a special science laboratory fully equipped for practical experimental work by a class of twenty to forty pupils, or a room less specialised in its equipment but furnished with flat-topped tables and chairs, a fixed bench with gas connections and a sink, and some storage cupboards. Rooms of this type, usually known as practical-work rooms, have been provided in a considerable proportion of London elementary schools and have proved of great value, as they can be used in the dual capacity of class-room and science-room. As a rule the practical-work room is the "home" of the top class (or of some special class), which finds the use of tables and chairs, instead of the usual desks or forms, a welcome change and much more adaptable for modern class-room work. When the room is required for special science purposes by another class, an exchange of class-rooms takes place for that lesson, and by this means the upper classes of the school have the advantages of a specially fitted and equipped room. This room may be used for practical lessons in subjects other than

science, such as geography, handwork, and needlework.

In groups (*b*) and (*c*) there will usually be provided laboratories or other rooms specially equipped for practical science. The type of equipment provided and the amount of apparatus available may (and actually do) vary over a very wide range. Thus, a recent "Report of an Enquiry into the Conditions affecting the Teaching of Science in Secondary Schools for Boys in England,"[1] issued by the Board of Education, shows that in thirty large schools visited for the purpose of the enquiry the expenditure on apparatus and material for instruction in science, other than nature study, varied from 1*s.* 8*d.* to 20*s.* 3*d.* per pupil per annum. The provision of special teaching staff may also vary over a wide range from schools in which there is no specialist science teacher at all to schools where there are one or more highly qualified science specialists. But, generally speaking, in the more progressive education areas, special provision for instruction in science, usually including practical work, is made in

[1] H.M. Stationery Office. Price 3*d.* 1925.

all schools providing education beyond the age and scope of the ordinary elementary school.

The question now is, What can, and should, be done in the way of science teaching in a system of education which involves so many types of schools and so much variation of facility and possibility within the same type? The answer is not so difficult as it might at first appear, for in broad terms the problem resolves itself into:

(*i*) What science should be taught in our elementary schools, and how should it be done? In other words, what science are we going to teach to the 90 per cent. of our school population who cease to attend day schools immediately after they have reached the age of fourteen years?

(*ii*) What science should be taught in our secondary schools and in other schools and institutions providing further education to the 10 per cent. of our elementary school population who remain at school for some years after the age of fourteen?

I propose to deal mainly with the problem of elementary school science teaching, as this is the larger problem (at least in numbers),

but in much that will follow the distinction between elementary and secondary instruction need not be emphasised, for many of the suggestions given will apply equally well to both types. The actual degree of application and the intensity of the instruction will necessarily not be the same in elementary as in secondary schools, but the aim and spirit of the teaching may be common to both types of school. We have also to remember that there is now in several parts of England and in Scotland a class of elementary school which gives a course of about four years commencing at the age of eleven to twelve years, and in some of the schools of this class (for example, the London Central Schools) excellent facilities are provided for science instruction ; these schools possess up-to-date and well-equipped laboratories, a reasonable and adequate allowance is given for apparatus and material each year, and specially selected teachers qualified in science are appointed to give the instruction. It is therefore possible in schools of this type, though classed as elementary schools, to undertake a serious and useful course in science. Moreover, these schools,

like the ordinary [1] elementary schools, are not hampered by the restrictions of examination requirements, and are, therefore, free to give the course of science which appeals to the head teacher and the science staff. This is an enviable state of affairs and one not enjoyed by secondary schools where the syllabus has generally to conform to the requirements of some external examination, so that, however revolutionary may be the views of the science teacher, he has to restrain his originality and teach according to an imposed scheme in order that his pupils may be able to pass certain examinations. I realise that it is difficult to break away from traditional methods, and that in most secondary schools it will be impossible to make drastic alterations in the existing science courses until the lead is given by the external examining bodies whose examinations are taken by the secondary schools. But teachers even in these schools can do something to broaden the basis of their science teaching, and to help to

[1] "Ordinary" is used here and later as meaning "non-central," to distinguish these schools from central schools which are also classed as "elementary."

humanise the study of the subject, even if, at the same time, they have to bring their pupils up to the standard of the external examination requirements in certain branches of the subject.

CHAPTER V

SOME PRACTICAL SUGGESTIONS

In this chapter I propose to indicate some definite ways in which the science teaching of our schools may be improved. The recommendations made do not refer to any particular branch of science; they are applicable to most of the science subjects suitable for study in schools and to most types of schools. In other words, they are general suggestions for the consideration of the teacher, who may adopt such of them as appeal to him.

(1) The first suggestion is to *endeavour throughout the science course to maintain the interest and keenness of the pupil.* Most of us are well aware with what enthusiasm the average pupil approaches his first science lesson. If a laboratory is available, he looks forward to the day when he will enter it, and be allowed to experiment there and to find out so much that he has wanted to

know. But this enthusiasm may be just as great and as real among pupils in schools where no special facilities exist for individual work. It is inherent in the pupils—a stage in their natural development—and the teacher should see that he makes the most of this desire to learn about natural and mechanical things, and that he does nothing that will kill the keenness of his pupils. He has a splendid opportunity, if he only seizes it. The longing to know about the things he teaches is there, and if he fosters it and keeps it alive, it will supply sufficient momentum to carry him and his class over a long course, even if the course includes ground where progress must necessarily be slow and difficult. And how often do we find this excellent opportunity lost and the keenness of the pupils killed within a week or two of their entrance upon the course! For it is not uncommon to find schools where the teacher is so imbued with the idea that his science teaching must be based on the sound basis of measurement that he commences his course with a lesson which includes the definitions of the yard and metre as units of length, and then sets his pupils a series

of exercises in measuring lengths of lines, straight and curved, in inches and centimetres, in finding the relation of the circumference of a circle to its diameter, in converting inches to centimetres and *vice versa*, and so on through a slow and dull and tedious course of measurements of length, area, and volume. These things may be necessary, but this introduction to science is hardly the happiest one if the teacher hopes to keep alive the freshness and interest of his pupils. His pupils are almost certain to feel disappointed and to think that their hopes of learning something of the wonder and mystery of science have been blighted. The remedy in this case is easy: measurement of this type should be transferred to the mathematics or arithmetic lesson; practical work of this nature will make the arithmetic lesson more interesting and real, and its banishment from the science lesson will remove a dull chapter from the romance the pupil hopes to find in his science studies.

To maintain interest and keep alive the natural keenness of the pupils should be the constant endeavour of the teacher, and if

he sees he is not succeeding in this, he must admit he is not making the right appeal to the class. He should keep in mind the value of the interesting experiment—the experiment which will set his pupils talking, in school and out of it, about the wonderful things they have seen or done in the science lesson. He should, on every suitable occasion, introduce an experiment which will arrest attention by its striking results; he should do things occasionally as a class demonstration on a large scale rather than let the pupils try them in so small and ineffectual a way that it demands from him an explanation of why the results are not quite as they should be. As a general rule, one big convincing and striking experiment is of more value than half a dozen little experiments which do not clearly show what the pupils set out to discover.

I do not wish to suggest that all science teaching should be spectacular, or that the pupils should regard their teacher as a sort of magician or wizard, but I do believe that there is room for this type of demonstration or lesson in the general scheme of science teaching. With boys, particularly,

there is much to be gained from it; they may be induced to try to repeat such experiments at home or elsewhere, and in this way their science lessons may develop in them the study of science as a hobby and as a useful and pleasant recreation in their leisure, not only while at school but probably also in later life. With this aim in view it is a good thing for the teacher to show his pupils that experiments can be performed with home-made apparatus, with tin cans, tumblers, and odd pieces of material, as well as with the more conventional and expensive apparatus usually found in laboratories. Several distinguished men of science—for example, Kelvin, Edison, and Davy—were keenly interested in performing science experiments when quite young, and practically all our famous scientists commenced their study of science through the impulse of interest, and continued their years of labour and of patient research because they retained this interest and enthusiastic eagerness. So with our pupils; they must have their enthusiasm kept fresh and keen throughout the course.

(2) The second suggestion is that *the*

teaching should be kept on as broad a basis as possible. This suggestion has a double application: it refers to the syllabus and also to the actual lesson. As regards the syllabus, we have already stated the case for making the science course a broad and a general one, on the grounds that such a course will be of more interest and value to the bulk of the pupils and students in our schools and colleges, and we shall have more to say on this topic later. There are, however, schools in which the teacher may have little or no choice in the course of science he has to teach, or where examination requirements prescribe more or less the course he must follow; there are also, particularly in higher institutions, cases where highly specialised courses in one particular branch of science are essential, and in such cases the counsel to make the syllabus broader and more general is impracticable and it may be ill-advised. But even in these cases the treatment of the subject is in the hands of the teacher. The actual lesson may deal with some particular topic, but the teacher is at liberty to treat this in a narrow sense or to introduce into his teaching material

and illustrations culled from a wide field of knowledge and experience. An illustration may make this clear. One teacher may give his pupils a lesson on the principle of Archimedes and be content when he has demonstrated, with the aid of one or two simple experiments, the truth of a certain statement which they will then proceed to memorise. Another teacher, in the same circumstances, would not consider he had finished his lesson until he had discussed with his pupils the many and varied illustrations and applications of the principle to be met with in different phases of modern life and work, such as ships and their cargoes and the meaning of the Plimsoll line, floating docks, the salvaging of sunken vessels, the diving and rising of submarines, the use of balloons and airships. Similarly, while one teacher will confine his illustrations in a lesson on "the three states of matter" to the case of water in the form of ice, water, and steam, the better informed teacher will tell his class about molten metals, the simple story of the earth, how iron and other metals are obtained from their ores, about the constitution of the sun and other stars, about

liquid air, about liquid and solid carbon-dioxide, about the use of fuses in electric installations, and so forth. These will serve to illustrate the suggestion we are considering. The more widely read and well informed the teacher is in all branches of science, the more illustrations he will be able to introduce and the more interesting and valuable will be his lesson. If the lesson is one in physics, the illustrations and applications need not be confined to those relating merely to the province of physics. They should be drawn from all realms of science, natural, physical, chemical, and biological. Science teachers should be, in the real sense, natural philosophers; by all means let them be expert chemists, or expert physicists, or expert botanists, but let them also have, besides this special knowledge of one or two small parts of the domain of science, a general working knowledge, and appreciation, of what has been done in other fields of scientific work. There was much interesting material in the old text-books of Physiography, and it is gratifying to find new text-books of general science beginning to appear in which excursions are made into the realms

of the different sciences and illustrations are drawn from all phases of life and activity. Recently a number of books of this type have been written and published in America, and now books on somewhat similar lines are beginning to be produced in this country. I do not suggest that this type of text-book is the one and only type of book which should be used, for it certainly is not; there is still a place for the text-book which deals in detail with some particular branch of scientific study, but there is also room for the science text-book which is informative and interesting in its broad survey of the big topics in natural and physical science.

(3) This mention of text-books brings us to the next suggestion, which is that *a science library should be an essential part of the equipment of every school where science in any form is taught.* One is accustomed to find libraries and collections of scientific books and other publications in the science departments of universities, technical colleges, and institutions where advanced teaching is provided. But it is not by any means common to find a suitable collection of

books of scientific interest in our secondary and elementary schools. These schools may, and usually do, have their school libraries, but such libraries are generally conducted as an activity associated with the study of English, and science books have not found a place in them. From personal experience I have found the science library a wonderful aid in the teaching of science, and even in elementary schools where the teachers have built up small libraries of simple books of general scientific interest written in popular style but accurate as to facts, the results have amply justified the enterprise. The pupils, particularly the boys, eagerly read these books at odd moments in school and during leisure hours at home. In this way they acquire a wide knowledge of general scientific facts and learn much of the triumphs of scientific achievement in past and present times; they read of the efforts of early pioneers and obtain a good general knowledge of aspects of science which it would not be possible for the teacher to deal with in the time at his disposal for class teaching. There is also the further advantage that these pupils, most of whom will leave school

shortly after they have reached the age of fourteen, enjoy reading of this nature so well that they will continue it after leaving school by obtaining similar books from the public libraries. This is a valuable point and an end worth working for. No school, elementary or secondary, need have the slightest difficulty in building up a small science library; hundreds of suitable books are now available and are appearing almost daily; many of these are attractively illustrated, are written in good language, and contain matter which is scientifically sound; further, they are not expensive, and can be procured a few at a time until a useful and varied collection has been obtained. The teacher should select books which will make the library cover a wide range of topics, so that his teaching will be supplemented on the part of the pupils by reading in other fields of study. The collection should include books dealing with topics in physics, chemistry, biology, astronomy, geology, and nature study; with the triumphs of engineering and other industries; with the romance of scientific discovery and of invention; and with the lives and achievements of

famous men of science. Lists of books of this nature are given in the Appendix (page 155).

(4) Allied to the preceding suggestion is this one—*the display in the class-room or laboratory of pictures and illustrations of scientific interest.* One rarely sees a picture or illustration on the walls of a science room. An "atmosphere" can be given to the room or laboratory by the use of pictures and illustrations. It is not difficult, in these days of illustrated papers, to collect reasonably good material to display on the walls and elsewhere. A centenary celebration of the birth or death of a famous scientist, or of some important discovery or invention, is always accompanied by appropriate illustrations in our daily newspapers and elsewhere. These should be displayed in the room, discussed, preserved for some time, and the best of them added to the general collection. At the time of writing the Railway Centenary is being celebrated and much general interest has been aroused by newspaper and other accounts of the celebrations and by illustrations. A lesson at such a time on the development of railways and steam

locomotives during the past hundred years would, therefore, be very profitable. Similarly, throughout the course of every year topics of general scientific interest are brought to the notice of the public. Many of these form suitable subjects of discussion in the science lessons, and the teachers should make use of such opportunities. Portraits of famous scientists with brief notes on their lives and achievements are also useful. The teacher will find that as soon as it becomes known that he wishes these things, his pupils will surprise him by the quantity of material they will bring for the common use; some of this material may often be of more than ordinary interest.

(5) If the previous suggestion is adopted, there will be little need to advise the teacher to *introduce into his teaching, whenever practicable, the names of famous scientists* and to make reference to the work which has made them famous. The lives and achievements of such men are always sources of inspiration, and their early efforts and final successes seldom fail to stimulate and encourage even young pupils. With older pupils the study of a certain amount of the *historical de-*

velopment of the subject will prove profitable.

(6) As part of the instruction there should be included in the course *visits to places of scientific interest* by the class, under the guidance of the teacher or some other qualified person. The places visited will depend upon the subject studied. A class having a course of nature study should have opportunities for studying nature at first hand by means of visits to the country, to the public parks, and the school garden if one exists. Similarly, for a senior class, even of an ordinary elementary school, studying general science, including simple physics and chemistry, there should be included in the course visits to places of industry and of scientific interest where the pupils may have an opportunity to see the industrial applications of certain scientific principles and processes. Some of these places may not be very closely connected with the actual study undertaken, and may even, to some, appear to be beyond the scope of the comprehension of elementary school pupils, but the capable teacher can usually make good use of such a visit for educational purposes. Places like gas works, electric generating

stations, soap works, fire stations, glass works, iron foundries, coal mines, engineering works, or a large ship, never fail to interest children, and the teacher can always find in them something which will make a strong and lasting appeal to his pupils. The amount of teaching that should be given before such a visit by way of preparation, or after the visit, or during the visit, will depend on the age of the children or students and on their technical knowledge. In town schools the science teacher should endeavour by means of these visits to give his pupils some simple explanation of important local industries and manufactures, and try to evoke an intelligent interest in them. Of a similar nature are visits to museums and other local collections of scientific value. London is fortunate in this respect in having the Science Museum, South Kensington, which contains excellent and interesting material and working models to illustrate certain branches of science. There is also, near it, the Natural History Museum.

(7) The teacher who has not yet made the experiment of having occasional *lecturettes*

by his pupils will, on making it, be surprised at the quality of the talks and the helpful effect they have on the general science teaching. The experiment may be carried out in different forms. In some schools small scientific debating societies are formed, membership being confined to the pupils of the senior classes; these may be run by the pupils themselves with their own elected chairman and other officers, or the teacher may serve as chairman and generally supervise the meetings. A programme of regular meetings (either in school hours or in the evenings) is prepared, at each of which short lectures and simple demonstrations are given by individual pupils, followed by discussion. In other schools the practice is less formal; the teacher merely prepares a programme of lectures and arranges for these to be given by pupils interested in the subjects at some particular meeting of the class. One might be inclined to regard such a scheme as suitable only for secondary schools and colleges, but having seen it in operation in ordinary elementary schools, I have no hesitation in recommending it as suitable even for such schools, provided the teacher sees the meetings

are properly conducted. The scheme has certain positive advantages ; it creates an activity connected with the science classes which may exist as a separate entity, and thus serve the purpose of adding to the time allotted to definite science instruction in the school time-table by occasional meetings and by preparation for them after school hours. Further, the scheme gives a pupil who has some particular scientific hobby or interest an opportunity to describe and discuss his interests with the rest of the class ; it enables topics to be discussed which would not otherwise get a place in the syllabus because of the difficulty of fitting them into the progressive scheme of teaching. Moreover, the preparation of the lecture by the pupil forms a valuable exercise in independent investigation, in the accomplishment of which he gains a training in self-reliance which will be of use to him in later life. The rest of the class, too, are almost bound to think before the meeting about the topic to be discussed, while at the meeting an atmosphere of interest will be created, and of this the teacher can make use at the end of the lecture in order to "drive home" the main

points discussed during the lecturette. The teacher's position is important; he may keep in the background during the lecture and discussion, but he must also be prepared to help and advise at suitable opportunities, and finally to "round off" the lecture at the close by focussing attention on the main principles raised. The teacher will have no difficulty in finding suitable topics for these lecturettes. The pupils themselves may possibly supply some, but the following suggestions will show the type of subjects which can be discussed: driving a tram-car, uses of electricity, aeroplanes, submarines, fireworks, seaweeds or flowers or butterflies collected during the school holidays, soap-bubbles, wireless, the telephone, eclipses, sundials, the steam-engine, the motor-car, and biographies of famous scientists.

Some science teachers keep a *question-box* in the class-room and into this the pupils drop written questions on points which have occurred to them and which they wish to have explained. Discussion often arises from these questions, and in such cases this device may be regarded as a less well-organised form of the foregoing suggestion about lecturettes.

(8) Wherever possible *specialisation* in science teaching should be adopted. The practice is common in the best secondary and central schools, but in ordinary elementary schools there is still some hesitation to adopt it. I have had opportunities of seeing the science work of many elementary schools in some of which the subject was taught by a class teacher or teachers with special liking, and sometimes special qualifications, for the work, while in others the instruction in each class was left to the respective class teacher. Generally speaking, the work in the former case is infinitely better than in the latter, where there is no specialisation. In the former case, apart from the better results usually obtained by a teacher teaching the subject he likes and knows best, there is the gain in continuity in the study from class to class, a matter of extreme importance in all schools. In some elementary schools where specialisation is adopted the science teaching is confined to one teacher, while in others it may be shared by two teachers, one taking the work of the lower half of the school and the other that of the upper half. This latter arrangement works

satisfactorily where, as in many elementary schools, the syllabus is divided into two main portions—nature study in the lower half and some general physical science in the upper. It is, as a rule, hardly advisable in an elementary school which does not contain more than 400 pupils to share the science teaching as part of a specialisation scheme between more than two teachers as indicated above.

(9) The value of handwork as an educational subject is now recognised, and in all modern elementary schools instruction in handicraft of some kind is given to both boys and girls. This course is often quite independent of the course in science, but occasionally one finds attempts being made to correlate the handwork and science. Where this has been done well, the results have been well worth the trouble, and both the handwork teaching and the science teaching have benefited. I do not wish to stress unduly the principle of correlation, but there is one point of contact between science and handwork which I feel is important, and which I have seen used so successfully that it should be included among

the suggestions contained in this chapter, and that is the *making of models and pieces of scientific apparatus.* Even in ordinary elementary schools I have seen some very creditable handwork of this nature. There are many things connected with the science lessons which can be made by boys with very simple tools and a small amount of wood and metal. These can be made during part of the handwork lesson, or during part of the science lesson, or even in the pupils' spare time in school or at home; they may be the work of individual pupils or they may be the collective work of several. The joy of completing something which works or functions is very great, and the teacher will have no difficulty in maintaining the pupils' interest in work of this kind. Electricity lends itself admirably to this sort of thing. Working models of motors and dynamos, simple electric and magnetic devices and pieces of apparatus, bells, telephones, and wireless receiving sets can be made or assembled even in an ordinary class-room. The work is light and easy, and it is surprising what results can be obtained with very simple and inexpensive

material. In certain cases it may be desirable and economical to purchase various items and fittings to be used in building up more elaborate models or pieces of apparatus. Work of this nature is possible in elementary schools ; it can be done in more elaborate detail and with better finish and workmanship in those central, technical, and secondary schools where special facilities exist in the form of wood and metal work-shops containing special equipment and machinery. I have seen some excellent work done under these conditions ; and without hesitation I can say that both the science and the handwork have been made through it more attractive to the pupils.

The foregoing suggestion concerns the teaching in boys' schools more than in girls' ; but where the subjects taught to girls are the same as to boys, there is no reason why the making of simple working models and of pieces of apparatus to illustrate the science work should not be attempted by the girls. Where domestic economy is taught to girls, it is, of course, possible to correlate the science with it.

CHAPTER VI

METHODS OF TREATMENT IN THE LABORATORY OR CLASS-ROOM

In this chapter I wish to discuss different methods of treatment and presentation. Various methods have been advocated and are in use, and, doubtless, will continue in use whatever may be said for or against them. For in each of them there is something to recommend it, and each, in the hands of a capable and enthusiastic teacher, can be made very successful. *The card system* is frequently found in use in universities and in schools of advanced instruction. It is useful as a system of conducting the practical work of a number of students working individually or in pairs. The student is given a card on which are set out instructions regarding the experiment he is to perform. The apparatus required is detailed, and either some theoretical account of the principles involved is given or reference is made to a text-book in which

this will be found. The student reads the instructions, studies the theory involved, and proceeds with the experiment. The weakness of this system lies in the fact that for convenience, and in order to make the most economical use of the stock of apparatus in the laboratory, each student cannot go through the course of experiments in the best and most logical sequence—one takes the first experiment and may then jump to the tenth, so that unless he supplements his practical work by a considerable amount of reading, his experimental work will not keep pace with his class theoretical work. With advanced students the danger is not great, but with pupils in junior forms of secondary schools and in elementary schools the system is open to objection on these grounds. In schools of this nature the advantages to be gained from class treatment and from general discussion of procedure and of results are too important to be lightly discarded for a system which, while it keeps the pupils interested in isolated pieces of experimental work, too often consists of a number of unrelated and discontinuous exercises in which there is no graded progression.

The *concentric system* finds favour with some teachers and can be used successfully. The teacher decides that a course of science covering mechanics, heat, electricity, and chemistry is to be spread over, let us say, four years. In the first year of the course he breaks a certain amount of ground in all four subjects ; in the second year he extends the range of his lessons in the four subjects, and so on year by year ; in each successive year his circles keep widening and the four subjects are dealt with more intensively. There is much to be said for this system in preference to one in which one subject is taken each year, treated exhaustively, and disposed of before the next subject is taken up. It is most successful where the teaching is in the hands of one teacher, for he preserves continuity in the teaching, and keeps his expanding circles concentric. Where the teaching in successive years is done by different teachers there is apt to be too much repetition and the subjects lose their freshness and power of appeal. The teacher who adopts the concentric system must see that he does not exhaust the charms of one subject in the first year. Each year's course

should have its own share of attractions; there must always be some new problems to solve, new difficulties to overcome, and new mysteries and wonders to explore.

Some teachers advocate and adopt an *historical treatment* in their teaching of science. Their course in dealing with a particular branch of the study follows the historical development, and so their pupils arrive at a knowledge of modern scientific principles and theories by the stages through which these have passed in the actual course of their development. I have seen chemistry courses on these lines which have been well thought out and have proved very successful. There is, in tracing the growth of a theory through the slow stages of its evolution, a fascination which appeals to pupils and students. The human side, too, is continually before the student, and the development of the subject from the crude first attempts at framing hypotheses to the refinements of modern theories and methods of investigation forms an attractive course of study. This method is more suitable to senior than to junior students. Further, it demands for its successful treatment a teacher who has

made a thorough study of his subject and of its history.

There is another method of treatment which, for want of a better name, may be called *the topic method*. This method has the advantage of breaking down the more traditional methods to be found in most schools. It will not be found in schools where the course is prescribed by the requirements of external examinations, but in ordinary elementary and central schools, and in some technical and secondary schools, the method is a possible and an interesting one. The science course, instead of consisting of a series of subjects like physics, chemistry, botany, etc., consists of a series of topics around which the science lessons are grouped. For example, one such topic might be "water," and on this would be given a series of lessons, with the necessary experiments, dealing with the physics and chemistry of water, with its uses in everyday life and the part it plays in nature. There would be included lessons on evaporation and condensation, and some account would be given of a town's water-supply. Similarly, an interesting series of lessons may be

arranged dealing with the topic "air." These would cover ground normally dealt with in separate courses in physics, chemistry, hygiene, and biology. The lessons would include the physical properties of air and of gases generally; the chemical composition of air; the properties and importance of oxygen, nitrogen, and carbon-dioxide; the part these gases play in animal and plant life; combustion; ventilation; compressed air; liquid air; respiration; the supply of air to divers, tunnellers, airmen, mountaineers, and men in submarines; etc. Further illustrations need not be given. Those already given will suffice to show the principle. The teacher who has read widely will find it possible to frame a good course which will introduce material and illustrations from all branches of science while keeping before his pupils one central topic around which his lessons are grouped.[1] A classical example of this

[1] Teachers will find "The Science of Everyday Life," by Buskirk and Smith (Constable), an interesting illustration of this method of treatment. This book is typical of several included in the list given in the Appendix (page 156) and will be found helpful to teachers of elementary general science.

method of treatment will be found in Michael Faraday's "Chemical History of a Candle," a series of lectures delivered by this great scientist to an audience of children at the Royal Institution at Christmas 1860. Around the central topic of the candle Faraday builds up an interesting series of lessons in general science, including the study of air and its constituents; the action of heat on solids, liquids, and gases; capillarity; respiration, etc.; he presupposes no previous knowledge on the part of his audience, but digresses as he finds it necessary in order to explain or amplify some phenomenon associated with his candle. The science teacher would do well to re-read these lectures in the light of his own teaching. He will always discover in them something new and interesting which he may be able to apply to his own teaching.

No special observations seem necessary on the more generally adopted method of treating each branch (such as heat, mechanics, electricity, chemistry, or botany) of the science course separately and finishing the study of this before proceeding to the next branch. I do not wish to stress the claims

of any particular method of treatment, for I believe the choice should be left to the teacher. The conscientious science teacher gives careful thought nowadays to these matters, and he should be left to try the method of treatment he thinks best. He may adopt none of the methods discussed in this chapter, but may have worked out a method which includes the best parts of each, and in this he has made a wise decision. If he has wide interests, and holds clear views on the aim of his science teaching, he may safely be left to follow the treatment which appeals to him.

Quite distinct from the general method of treatment of the syllabus, the teacher will continually be faced with the problem of how best to conduct his actual lesson. The problem will be understood better from an example. Let us assume the teacher is giving a course in electricity. Is he to follow the lines along which he was taught his science, and which are still largely followed, of establishing certain principles step by step and then seeing how these are applied in industry and in everyday life? In other words, is he to begin by rubbing pieces of

glass, amber, and sealing-wax with silk and cat's fur ; to play with pith balls and the electrophorus ; to learn the laws of induction, of attraction and repulsion ; and so on through a long and probably logical course before he is allowed to handle or investigate a real piece of electrical apparatus in common use ? Or is the teacher to hand over to his pupils an electric bell, say, bits of wire, and some cells, let them work with these for a time, and then proceed to discover how and why they work, and from a study of these build up a systematic knowledge of the principles and scientific laws upon which they depend ? I think the latter course will be found the more interesting, and it can be made just as logical. Generally, it will be wise to start off with something the pupils know of in a general way, with something they are interested in, which, if possible, they can work with and take to pieces. The parts of this should be analysed bit by bit to discover the principles involved ; these principles should be investigated separately, tested by further experiments, and then additional examples of their application in the service of man or in natural phenomena

should be sought. The principles discovered and demonstrated in this way can finally be built up into an ordered whole, and this completes the process. This last step, however, is more than can be accomplished with pupils in the elementary school or in the lower forms of secondary schools.

The question of how much of the work should be done experimentally by the pupils has been raised in Chapter II, where it is pointed out that a purely experimental course on more or less heuristic lines has the unhappy effect of very considerably restricting the scope of the science studied and of bringing into undue prominence certain aspects which are of little or no value in after-life to more than 90 per cent. of the school population. There are so many topics of importance in our everyday life which would be of interest (general, vocational, or cultural) to the majority of our pupils after they leave school that the first duty of the teacher should be to see that he has included these big things in his syllabus before he descends to the smaller and less important things of a particular branch of science. And he can only do

this by curtailing some of the slowly performed experimental work of the pupils and replacing part of it by demonstrations (in which, of course, the pupils may assist if possible) and by supplementing this practical work by talk, discussion, and general reading. Let the pupils, by all means, make experiments, let them construct things and do things, but let such experiments as they attempt be clear and convincing in their results so that the pupils acquire some small sense of the law and order of science.

The mistake of attempting too much experimental work on the part of the pupils does not occur in schools where no provision for practical work exists. But, unfortunately, in many of these schools this lack of special provision for practical work is made the excuse for little or no science being included in the curriculum. This need not be so, for there is much that can be done without such special provision. The willing teacher will find much good experimental work which his pupils can do in the ordinary class-room (for example, simple electrical and magnetic work suitable for elementary

schools); he may also demonstrate his lessons at an ordinary table—water can be available in a bucket, and if he cannot contrive a fitting for a Bunsen burner, he can use a spirit lamp. In this simple way, and with a small amount of inexpensive apparatus, very good and very useful work can be accomplished which will be found suitable to the requirements of elementary and other schools in which special facilities for practical work do not exist.

Finally, I wish to warn teachers against the use of phrases and scientific expressions which are quite meaningless to the pupils. These may, in some cases, be learned and repeated correctly by the pupils, but it does not follow that they are understood. A short cross-examination of the pupils soon discloses that. I have heard pupils in elementary schools give correct definitions or statements of specific gravity, specific or latent heat, or of Boyle's Law, or the principle of Archimedes, but many of them did not understand what they meant. I have even heard, and that quite recently, a teacher teaching his boys in an ordinary elementary school to recite the statement that "a liquid boils

when its saturation pressure equals the pressure to which it is subjected," or something equally incomprehensible to them! Phrases of this type are nothing more than useless scientific jargon; they confuse the pupils and, when they are recited correctly, they give the pupils a false impression of knowing the science they have studied. The use of such expressions persists in schools where the "academic" study of science has still too strong a hold, or where the teacher is in the unfortunate position of not knowing the subject sufficiently well; this lack of knowledge usually compels him to follow closely a particular text-book, which too frequently is a relic of his bygone student days and may not be the best for modern elementary schools.

CHAPTER VII

WHAT SHOULD WE TEACH?

IN the preceding chapter various methods of treatment have been discussed. These are, generally speaking, applicable to most of the subjects into which science is divided, and we have discussed them without special reference to the actual science subject or subjects to be taught. I propose, in this chapter, to sketch in broad outline a scheme showing possible subjects for treatment in schools according to the approximate age of the pupils. It will be realised that any scheme of this nature, if it is to apply to the many different types of schools contained in our educational system, must not be interpreted in any narrow sense; considerable latitude must be allowed so that variations and departures may be made to meet the requirements of individual schools and in accordance with the tastes and qualifications of individual teachers.

If it is possible to divide our school population into groups in each of which some definite suggestions for the content and treatment of the science course can be formulated, it seems to me that the minimum number of such groups is four. These groups are as follows:

I. The first group would contain all pupils up to the age of about eleven to twelve years. At this age there occurs the first parting of the ways, and the school population divides up into three main sections:

(*a*) Those who continue in ordinary elementary schools and leave school at the age of fourteen years.

(*b*) Those who proceed to secondary schools, or equivalent institutions, for a course of higher education lasting for from five to seven years or more.

(*c*) Those who proceed to central schools, or their equivalent, for a four years' course. This course is usually of a less "academic" or "bookish" nature than that of the secondary school, and is provided by education authorities without payment of fees. It may be regarded as an extension of the ordinary elementary school.

These three sections, which are determined by our national system of education, form the basis of our next age groups.

II. The second group would contain all pupils who remain in ordinary elementary schools. Their ages would range from eleven or twelve to fourteen or fifteen.

III. The third group, for purposes of science instruction, would include pupils of ages from eleven or twelve to fifteen or sixteen, whether in central, secondary, or technical schools, or their equivalents. Pupils in these schools may be grouped in one class for this purpose because, as a rule, these schools have facilities for definite science teaching and usually include among their staff a specialist teacher of science.

IV. The fourth group would include all pupils and students beyond the age of about sixteen years who have taken a science course in Group III and wish, either from motives of interest or in preparation for industrial or professional employment, to continue their scientific studies.

The accompanying table shows the proposed grouping and the subjects which may be included in the course for each group.

Group.	Ages.	Subjects.	Remarks.
I.	Up to 11 or 12.	Nature Study (in widest interpretation). Common objects and phenomena.	Elementary and preparatory schools.
II.	11 or 12 to 14 or 15.	General treatment of important topics from one or more of the following: Hygiene and Physiology. Domestic Science. Weather Study. Astronomy. Physics. Chemistry. Botany. Geology. Biology.	Elementary schools. Pupils in this group proceed to no further education beyond possible attendance at evening schools.
III.	11 or 12 to 15 or 16.	General treatment, but of a more formal nature and with more elaborate experimental work, of important topics from one or more of the subjects enumerated in II.	Secondary schools. Central schools. Technical schools.
IV.	Above 16	Intensive study on specialised lines of one or more of the subjects enumerated in II, and possibly studied in III.	Secondary schools. Technical colleges. Universities.

The main principles which should be observed, so far as it is possible to frame any, are: (i) science up to the age of about twelve years, when the decision as to whether the pupil will have a secondary education is made, should be confined to the study of nature in all its phases, and of common objects; (ii) the formal study of the more exact sciences like physics and chemistry should not be commenced before the age of twelve years; (iii) the course for pupils who continue their education beyond the age of fourteen in schools offering instruction of a higher character than that of the ordinary elementary school should be on general rather than specialised lines; and (iv) specialised and intensive courses in any particular branch of science should not, as a rule, be commenced until after the age of sixteen and until the pupil or student has completed a course of at least four years' duration of the type indicated in (iii).

It will be observed that after the age of about twelve years the whole field of physical science is thrown open to the choice of the teacher. Until the pupil reaches the stage of advanced work (after the age of sixteen) the

course selected for him by the teacher should be as wide as possible and certainly wider than is commonly met with in schools to-day. I agree that the selection will continue to include, particularly in boys' schools, larger contributions from physics and chemistry than from other branches of science, but some attempt should be made to introduce contributions from other sciences, if only to make boys realise that science consists of more than physics and chemistry, and, in the case of girls, of more than botany.

In the next chapters consideration will be given in more detail to the subjects mentioned above, in order to indicate some of the topics which may be introduced into the teaching.

CHAPTER VIII

NATURE STUDY

I HAVE suggested that for pupils up to the age of eleven or twelve years the science course need include no more than nature study and some lessons on common things and familiar phenomena. I am well aware that this advice may be dangerous, for I have seen schools where nature study has formed the basis of the science course up to the age of eleven, where one or two nature-study lessons are given each week with systematic regularity, and yet I have felt that the course was not meeting the needs of the pupils and that it would probably have been better to have had no science teaching in the school at all. The fault, in such cases, lies in the interpretation put upon the term "nature study" and in the method of teaching the subject.

It is important to make it clear that by "nature study" I mean *the study of Nature*

in all its branches—plant, animal, and physical. Too often it is interpreted as a superficial or simple course of botany in which a few common flowers, plants, and trees are studied in relation to the seasons. An attempt is made to frame a syllabus covering four or five years' study and dealing with the seasonal appearance and development of common plants and trees, with the result that long before the age of eleven is reached the pupils are tired of nature study and of the four seasons. This need not be so, for if the subject is dealt with widely and the teacher is himself a lover of nature, he will find no difficulty in framing a syllabus which will cover a four or five years' course of study, which will give the pupils fresh material and topics to consider in each succeeding year, and which will keep them interested and give them an abiding love of nature.

The course should be made broad in its survey, should include studies of plant and animal life, and of natural phenomena (such as weather, the sun, the moon, day and night, etc.). And, to the fullest extent possible, nature should be studied at first

hand. Outdoor work is essential, even if it has to be confined to parks and open spaces; and when material is used in the class-room it should, for preference, be living material. Growing botanical specimens to illustrate lessons are possible even in town schools, and living insects and small animals can be kept for certain periods under satisfactory conditions and without cruelty.

The aim of the course should be to teach the children to make observations, to talk and write about what they observe, to acquaint them with the wonder and beauty of nature and with certain simple natural phenomena and processes, and to give them through this knowledge an appreciative love of nature and her ways.[1]

I do not propose here, or in connection with other subjects of the science curriculum, to give a scheme of work for the class-room, for the needs of individual schools vary so much and the syllabus should be the expression of the views of those who will be

[1] The excellent series of Nature Study leaflets issued by the School Nature Study Union (price $2\frac{1}{2}d.$ each, post free, from Mr. E. G. Clarke, Craig Rossie, Stanley Avenue, Wembley, Middlesex) will be of great help to the teacher of Nature Study.

directly concerned in teaching it.[1] But there are certain things which should be mentioned as worthy of the consideration of those who are responsible for framing the syllabus of a school.

(1) Quite apart from whatever knowledge the pupils may have of individual plants or flowers, or of the parts of a flower, they have not completed their study of plant life unless they have a clear, though simple, conception of the functions of the main parts of a plant or tree (i.e. the root, the stem, the flower, and the seed or fruit) and realise the cyclic process going on continuously year by year of germination, growth, and propagation.

(2) This cycle is common to all life—plant, animal, and human, and there is a perpetual process of birth, struggle for existence, growth to maturity, reproduction, decay, and so on throughout all nature.

[1] In the preparation of their syllabus and lessons, teachers will find valuable help in a report of a subcommittee appointed by the Science Masters' Association, published by the Oxford University Press under the title "Elementary Science, Nature Study and Practical Work in Preparatory Schools and the Lower Forms of Secondary Schools" (price 1*s*.).

Easy illustrations of this will not be difficult to find. Other cycles (such as water, evaporation, condensation, rain) and seasonal cyclic changes should be noted.

(3) The botanical part of the scheme should include the study of the more common wild and garden flowers (including bulbs) and trees. These should be studied as growing things and observations should cover a reasonable period of time. For example, each child might be given the task to observe, and make notes of, the growth, changes, and development of a typical flowering plant and of a common tree throughout a whole year at intervals of two or four weeks if specimens are to be found growing in the neighbourhood of the school. A continuous series of notes and sketches covering the changes throughout the four seasons would be a valuable exercise. With older children the range of their study should be extended to make them aware, at least, of the existence of lower forms of plant life such as fungi (for example, the mushroom and common moulds), algæ (freshwater and sea), ferns, mosses, and conifers.

(4) In schools fortunate enough to possess

a school garden, or even a small outdoor plot, experimental work will be possible, and this work, in the hands of a teacher who knows the subject, can be made thoroughly scientific and valuable. School gardening, unfortunately, too often consists of little more than sowing seeds and gathering in the harvest of flowers, vegetables, and fruit, little or no attempt being made to develop the scientific side of the subject or to show, by experiment, the effects produced under different conditions of light, heat, moisture, soil, etc. (See "The Teaching of Gardening": Suggestions for Teachers, issued by Board of Education. Price 2*d.*)

In schools where a school garden is out of the question, plants should be grown in the class-room and, if there is an outside source of supply, botanical specimens should be displayed and used. I know of more than one town elementary school in which considerable interest in the subject was aroused by the daily display, with suitable short notes, of natural history specimens brought by the members of the staff. When not in use in the class-room these were laid out on a table in the hall or corridor and were

examined and discussed by the pupils during their recreation and lunch intervals.

(5) With or without the facilities for school gardening, plant studies offer good opportunities for simple experimental work by children of elementary school age and for the introduction of some easy work in physics and chemistry. Experiments can be arranged to show, for instance, the effect of light on the growth of plants, the conditions most favourable to germination, the rates of germination of seeds and growth of seedlings, the giving off of moisture by plants (transpiration), the breathing of plants (respiration), the giving off of oxygen under certain conditions (photosynthesis), the pressure in plant stems, the feeding of plants, and the flow of sap through stems and leaves.

Experimental work of this type will necessitate the teacher's including in the course some simple lessons on air and water, temperature, evaporation and condensation, hydrogen, oxygen, nitrogen, and carbon-dioxide. The extent to which these topics are studied will depend on the age of the pupils; only the simplest aspects can be

touched upon with pupils below the age of twelve, but thereafter effective and interesting instruction is possible. The experiments can be performed without elaborate apparatus; it will be found convenient to have fitted broad window-ledges on which material and apparatus can be set up and left undisturbed for some time. These broad window-ledges also make good places for standing growing plants and specimens requiring light and sunshine.

(6) The course should include the elementary study of all types of animal life—birds, fishes, pond life, insects, reptiles, and animals—likely to come within the experience of children. The life histories of a few of them should be known—for example, the frog, the moth and butterfly, the silkworm—and if the stages in the development of these can be shown by having aquaria and breeding cages in the school, the instruction will be more interesting and effective.

(7) Visits should be paid to any natural history museum in the neighbourhood, and at least once a year there should be a nature ramble in the country.

(8) At this age the collecting instinct is

boys and girls is strong and they will require little encouragement to induce them to make collections of leaves, flowers, and other natural history specimens. Out of these collections, by careful selection, there may grow a useful school museum.

(9) Wherever possible, processes common to different types of life should be considered together. For example, it should be shown to children that the plant, as a living organism, requires, just as animals and human beings do, air to breathe and supplies of food and water to keep it alive. There are, too, several interesting examples of the interrelation and interdependence between plants and other forms of life which are not beyond the comprehension of children and which will give them a higher appreciation of the ways in which nature works. For example, the part played by birds, animals, man, wind, and atmospheric conditions in the dispersal of seeds; the services rendered by bees and other insects in the pollination of certain flowers and the return they receive for their services; the dependence of animals on plants for food, and the protection plants and crops receive from

certain birds which destroy harmful insects. Illustrations of this type will make clear to children in a simple way the "web of life," of which probably the best example is Darwin's chain of connection between cats and the clover crop: clover depends on bees for the fertilisation of its flowers, so that next year's supply of clover depends upon this year's supply of bees; but field-mice destroy the combs of bees and thus keep down the supply of bees; field-mice, on the other hand, are preyed upon by cats, and thus indirectly the clover crop depends upon the cats of the neighbourhood! A pretty illustration of the interdependence between bird, insect, and plant life will be found in "The Birds of Killingworth," one of Longfellow's "Tales of a Wayside Inn." A wider view of this interdependence is given in the following passage from Professor J. A. Thomson's "Introduction to Science": "'The rain falls; the springs are fed; the streams are filled and flow to the sea; the mist rises from the deep and the clouds are formed, which break again on the mountain side. The plant captures air, water, and salts, and, with the sun's aid, builds them up

by vital alchemy into the bread of life, incorporating this into itself. The animal eats the plant; and a new incarnation begins. All flesh *is* grass. The animal becomes part of another animal, and the reincarnation continues.' Finally, if we can use such a word, the silver cord of the bundle is loosed, and earth returns to earth. The microbes of decay break down the dead, and there is a return to air and water and salts."

(10) Natural phenomena should find a place in the scheme of nature study. There should be included lessons on clouds, rain, evaporation and condensation, thunder and lightning, snow, frost, ice, dew, the rainbow, sunshine and shadow, the sun, the moon and the stars, the seasons, and the relative motions of the earth, sun, and moon in order to explain day and night and the moon's phases. The mariner's compass, and the phenomena of attraction and repulsion in magnetism and frictional electricity, can be conveniently introduced into the scheme along with these lessons.

CHAPTER IX

HYGIENE, DOMESTIC SCIENCE, AND WEATHER STUDY

We have now to consider the science course suitable for children of from about twelve years onwards. These children will fall mainly into two groups: those who remain in ordinary elementary schools (Group II in the table, page 71), and those who proceed to secondary, central, and technical schools (Group III, page 71), where more advanced instruction is offered, and where, as a general rule, better provision in the matter of laboratory accommodation and specialist teachers of science is made than in the ordinary elementary school. In both of these groups I have suggested the same range of subjects from which the teacher should choose: namely, Hygiene and Physiology, Domestic Science, Weather Study, Astronomy, Physics, Chemistry, Botany, Geology, and Biology; for the difference

in the course suitable for each group should be one of treatment and not of subject. In both groups the teacher should aim at including in his scheme as wide a range of topics as possible, but the treatment in the case of pupils in Group III will be more exact and formal and will include more and better experimental work, for the course will be a longer one and more expensive apparatus and equipment will be available than in the case of Group II. The teachers in Group II will be perfectly free in their choice of topics, but many of those in Group III will be restricted by the requirements of certain external examinations; yet it is possible, even in the circumstances of those in Group III, to attempt something more than is now generally done to broaden the basis of the teaching—for example, by introducing illustrations and applications of principles and laws from branches of science other than the one actually taught, and by encouraging the pupils to read books of general scientific interest.

I propose, therefore, to discuss briefly each of the above subjects without particular reference throughout to Group II or III,

and to leave to the teacher the choice of what he considers suitable for his pupils and for his particular school.

Hygiene and Physiology

The transition from nature study, on the lines we have discussed, to an elementary course of hygiene and human physiology will be easy and natural. The subject will be found particularly suitable for girls (but not, therefore, unsuitable for boys), and in the teaching of it a laboratory is not essential, many of the experiments which will arise being possible in the ordinary class-room and with inexpensive apparatus. The course I have in mind would include, though not necessarily in the order given, the following topics:

(*a*) *Water.* (Sources; uses; properties and composition; purification; storage; supply to towns and homes.)

(*b*) *Air.* (Natural and mechanical ventilation; composition; impurities.)

(*c*) *Heating and lighting* (natural and artificial) of our homes and buildings.

(*d*) *Value of sunshine.*

(*e*) *Disease.* (Spread by air, water, food;

germs and bacteria; care of food; infectious and contagious illnesses; parasites; disinfectants, germicides, deodorants, and sterilisation.)

(*f*) *Disposal of sewage and refuse.*

(*g*) *Cleanliness.* (Personal and general.)

(*h*) *Body structure and functions of main parts.* (Respiratory, digestive, circulatory, muscular, and nervous systems; eyes; ears.)

(*i*) *Food and drink.* (Uses of food; kinds; constituents; temperance.)[1]

(*j*) *First aid and home nursing.*

(*k*) *Physical exercise in relation to health.*

Some of the above topics involve an elementary knowledge of certain parts of physics and chemistry, but it is not necessary that a course in physics and chemistry should precede the above course. The teacher will find it more convenient and more satisfactory to introduce, by way of digressions, the necessary physics and chemistry as the need for them arises. The above course is well within the range of ordinary elementary school children between the ages

[1] For this section the syllabus of lessons (with notes) on "The Hygiene of Food and Drink," issued by the Board of Education (price 2*d.*), will be helpful.

of twelve and fourteen. It will also prove a suitable introductory course for more advanced work with non-elementary school children. Some teaching of this nature should be given to all pupils because of its practical importance.

Domestic Science

This is a vague term; it is used, in many cases, to denote the course in cookery, laundry, and household management which is provided for girls in most of our schools, and which is too often regarded as no part of the science course of the school. Occasionally, in particular schools, the science teacher may co-operate with the domestic science instructress, and where this is done both courses stand to gain. The science teacher usually confines his or her teaching to the explanation and demonstration of the scientific principles underlying the processes which the girls learn under the direction of the domestic science instructress. Whether the work is done as part of the science course proper, or as part of the domestic course, the following topics deserve to be considered for inclusion:

(*a*) The topics stated above in the course of Hygiene and Physiology, amplified or added to as follows:

(*b*) *Water.* (Experiments on hard and soft waters.)

(*c*) *Heat studies.* (The thermometer; temperatures of boiling water, boiling fats; oven temperatures; effect of salt on boiling-point of water; combustion; conduction, convection, radiation, and absorption; application of these to clothing and to kitchen utensils; "hay-box" cookery; heat units, calorie and therm; steam and latent heat; heating by coal-gas, coal, oil, and electricity; domestic hot-water supply; the gas and electric meters; the thermos flask.)

(*d*) *Foods and their food values.* (Kinds of food; simple experiments on foods; how their food-values are estimated.)

Note.—The experiments on food which I have in mind are of the following type:

(i) Evaporation experiments. For example, to find the percentage by weight of solid matter in milk, vegetables, etc.

(ii) Milk. Its density and main constituents; the preservation of milk by pasteurisation.

(iii) Preservation of foods ; cold storage ; sterilisation ; preserving jars.

(*e*) *Methods of cooking foods.* (Boiling water ; boiling fats ; steam ; roasting, grilling, and stewing ; temperature effects ; "hay-box" and other methods depending on insulation.)

(*f*) *Solution and solvents.* (Water ; turpentine ; petrol ; benzine ; cleansing materials.)

(*g*) *Soap.* (Its manufacture and uses.)

(*h*) *Chemistry of the kitchen.* (Nature and action of common alkalies and acids ; sugar ; salt ; baking soda ; baking powder ; washing soda ; lime ; bleaching powder ; starch ; flour ; yeast ; bacteria ; fermentation, etc.)

Weather Study

For schools in which no systematic courses in physics or chemistry are given either because there is no laboratory for experimental work or because there is no teacher with the necessary specialist knowledge to give the instruction, a simple course of weather study will prove practicable and useful ; it also follows, without serious break, the course in nature study up to the age of eleven or twelve years. And it has this very

important advantage in addition—it will gather together in one course of definite practical value and interest certain essential and interesting parts of physics, chemistry, and astronomy, and so provide a good general science course which can be taught by a teacher not necessarily highly qualified in technical science. The course, too, offers excellent opportunity for simple experimental work which can be carried out by boys or girls in the class-room or in the open.

Meteorology has made very considerable progress during the last ten years. During the war the increase in aviation, the effect of the upper air in long-range gunnery, and the work of "sound-ranging" made acute the need for more reliable information regarding the weather. And to-day the need is as great. Civil aviation goes on daily, and it is important that weather conditions all over the world should be known. Seamen, too, require this information and the forecasts based on it, and so also do farmers. To obtain information there exists a wonderful system of agencies—meteorological stations, observatories, ships, etc.—which, by means of telegraph or wireless, forward

their observations to headquarters, where they are recorded, charted, and finally issued in convenient form as weather forecasts, weather charts, and other data. These weather data and forecasts are nowadays familiar to most people because of the publicity given to them by their being broadcast daily by wireless, and weather charts are published daily in our newspapers. Weather study should, therefore, have a place in our science course.

To begin with, very simple records can be kept which show the weather prevailing day by day. I have seen weather calendars kept even in infants' schools, the space representing each day being filled in with a simple pastel drawing symbolic of the weather—a brightly coloured picture with a large sun for a sunny day, a picture in which the umbrella plays a prominent part for a wet day, and so forth. Records of this kind can be elaborated as the children grow older. In the early stages they are merely "qualitative," but later the need for "quantitative" records will be evident, and this is the stage we are now discussing.

It is important that whatever records are

made should be *continuous* and should extend over long periods. Only in this way can general conclusions be made. For example, a few spasmodic temperature readings at odd intervals are of little value, but if daily (say, noon) temperatures are obtained for a year and are recorded in the form of a graph the children will see pictorially the seasonal changes in temperature. Further, if these are displayed alongside a graph showing the variation in the altitude of the sun throughout the year, the connection between the temperature changes throughout the year and the altitude of the sun at noon will be established. Similarly, a graph showing the change in temperature throughout the day obtained by taking hourly readings will, if compared with one showing the change in the sun's altitude throughout the day, establish the relation between the diurnal variation of temperature and the altitude of the sun. The question of the "lag" of these two series of temperature observations behind the altitude observations will not be difficult to explain.

The lessons in a course on weather study would group themselves round the three

main topics of temperature, moisture, and pressure, and there are accordingly given below some of the matters which should be included under these heads.

(*a*) *Temperature*.

(i) The sun as the source of heat; concentration by lens or spherical flask of water; methods of recording sunshine.

(ii) The effect of heat on solids, liquids, and gases.

(iii) The thermometer; temperature records; maximum and minimum temperatures.

(iv) Conduction, convection, radiation, and absorption of heat; simple absorption experiments with sand, dark earth, water, white and black surfaces exposed to sunshine; radiation experiments with similar materials.

(v) The cooling of air on expansion and the heating of air by compression.

(vi) Continuous records of sunshine, of daily temperature, and of the altitude of the sun at noon should be kept.

[*Note*.—The altitude of the sun at noon can be obtained from the ratio of the height of a vertical stick to the length of its shadow (by drawing to scale or by

reference to a table of tangents). If the actual angular altitude is not desired (and it is not necessary for graphical purposes), the length of the shadow of a vertical stick may be taken as a measure of the altitude; the shorter the shadow the greater will be the altitude, so that in plotting these the shadow-lengths should be measured *downwards* from the zero line in order to give a graph which will show clearly the variation in the sun's altitude throughout the year.]

(*b*) *Moisture.*

(i) Water; change of state; ice, water, water-vapour; latent heat.

(ii) Evaporation and condensation; effect of temperature on evaporation; cooling due to evaporation; wet and dry bulb thermometer.

(iii) Humidity; experiments to show the presence of water-vapour in the atmosphere, and how the amount present can be determined. Tables will show that for each definite temperature there is a maximum amount of water-vapour which can be held in the air. When this point is reached no more evaporation can take place; if the temperature falls, some of this vapour must

be deposited as water; and if the temperature rises, a larger amount of vapour can be held. If this is understood, the significance of wet and dry bulb temperature readings will be clear and the difference between a "good drying day," when evaporation goes on rapidly, and an "oppressive day," when the actual temperature may not be higher but when there may be so much water-vapour already present in the air that evaporation goes on very slowly.

(iv) Rainfall; methods of measuring and recording rainfall; clouds; hail; snow; dew; frost; mists and fogs.

(v) A rain-gauge should be made and observations of rainfall should be taken and recorded; rainfall maps should be studied.

(*c*) *Atmospheric pressure.*

(i) Pressure in liquids; methods of measuring.

(ii) The barometer. (Water, mercury, aneroid; the barometer as a measurer of heights of mountains and aeroplanes.)

(iii) Pressure differences and movement of air; winds; isobars; methods of measuring the force and velocity of the wind.

(iv) Use of weather maps ; wind forces ; cyclones and anticyclones ; monsoons.

(v) Daily barometer readings should be taken and graphed, together with "wind roses" to show the daily direction of the wind.

CHAPTER X

ASTRONOMY

In the preceding chapter I have stated briefly some of the topics which I think should be included in a science scheme for pupils over twelve years of age dealing with Hygiene and Physiology, with Domestic Science, or with Weather Study. In this chapter I propose to consider Astronomy as a school science subject in more detail because at present it receives little recognition in schools. There are very few schools, secondary or elementary, which include astronomy in the curriculum. This is unfortunate, for astronomy, besides being a very ancient science, is a very important one; it is of immense practical value in daily life, and includes in its purview many matters of general interest and information which should be known by all who claim to have had a liberal education. I am well aware that a school cannot hope to possess

the expensive and accurate instruments to be found in an observatory, and I know also, from personal experience, that certain practical work in astronomy has to be done during the night-time, and that a night's work, carefully planned beforehand and possibly even all but completed, may be wrecked by clouds and other accidents of our weather conditions. For these and other reasons the study of astronomy has been neglected in our schools. In spite of the difficulties, however, I think there is much in astronomy which lends itself admirably to school work and which entitles the subject to a place in the curriculum as a science worth teaching. As a popular study it is fascinating, stimulating, inspiring; and there is a wealth of literature, scientifically accurate and charmingly romantic, which will not fail to interest readers with no strongly developed practical or scientific bent. As an exact science it will appeal, with equal charm and fascination, to the mathematician. This wide range of appeal makes the subject particularly suitable for schools. In elementary schools the study would be confined largely to descriptive

work with a certain amount of simple observational work, while in secondary schools the course may be expanded to include mathematical work within the range of the pupils' mathematical knowledge, together with more accurate and technical practical work.

The following outline of topics, therefore, must not be regarded as within the range of possibility of all schools. The whole of the work outlined here could only be taken with senior pupils possessing a good working knowledge of secondary school mathematics. The teacher should choose those parts which he thinks will be within the capacity of his pupils. A lantern and a good collection of astronomical slides are desirable for the descriptive parts of the course. These can be obtained in most towns, but if they are not available, recourse should be had to suitable illustrations and diagrams. The course is equally suitable for boys and girls, and most of the practical work can be done in the ordinary class-room or play-ground, or at home or outside in the late evening, and with simply constructed apparatus and models.

(1) *History of Astronomy.* There are two main periods:

(*a*) Ancient astronomy and (*b*) modern astronomy, and these periods are separated by a gap of thirteen or fourteen centuries, from about the second to the fifteenth century A.D., during which the science made no substantial progress.

(*a*) *Ancient Astronomy*—up to the second century A.D.

A considerable amount of astronomical knowledge was acquired by the early Chinese (2000 to 3000 B.C.), the Hindus, and the Chaldeans. The Greeks (Thales, Pythagoras, Aristotle, Aristarchus, Eratosthenes, Hipparchus, and Ptolemy) systematised and added to this knowledge, raising it to the dignity of a science.

Early theories and beliefs; Ptolemaic system.

In this period we have the origin of the *Day*, *Month*, *Year*, and *Hour* as time-measures.

(*b*) *Modern Astronomy*—from the fifteenth century onwards.

The work of Copernicus, Tycho Brahé, Kepler, Galileo, and Newton.

The Copernican system; gravitation.

Modern advances due to use of accurate scientific instruments and to improved mathematics. (The telescope, the camera, the spectroscope, etc.)

The founding and history of Greenwich Observatory.

The work of observatories.

(2) *The Calendar.*

The Julian and Gregorian calendars.

Astrological origin of the names of the days of the week.

(3) *The Sun as a typical star.*

Nature and composition; its influence on the earth and on terrestrial life.

Distance and how measured. Aids to the appreciation of this distance.

Size of sun and how determined. Aids to appreciate size, volume, and mass of sun.

Photographs of sun's surface.

(4) *The Moon.*

Motion round the earth. The phases.

The lunar month.

Difference in time of passing a fixed point on successive nights.

Distance from earth and how measured.

Dimensions and how measured. Aids to appreciate distance, size, volume, and mass.

Appearance to eye, and in small telescope.

Photographs of moon's surface.

(5) *The Earth as a body in space.*

Its shape and how we know it.

Its size and how we measure it.

Its mass and how we measure it.

Aids to appreciate its size, volume, and mass.

Latitude and longitude. The nautical mile and knot.

Rotation. Day and night. Speed. Proofs of rotation.

Revolution. Signs of Zodiac. Proofs of revolution.

Form of orbit and how we know it. Velocity in space relatively to sun.

The seasons.

Experiments with gyroscope.

(With advanced classes—precession and precessional period.)

(6) *Eclipses.*

The sun-earth-moon system, and their relative motions.

Early superstitions.

Average dimensions of shadow cones of moon and earth.

Solar eclipses and lunar eclipses; partial, total, and annular. Phenomena during eclipses. Why eclipses do not occur every month.

Demonstrations with models. (The use of paper cones attached to spheres representing earth and moon will prove helpful. These paper cones will represent shadow cones and should be approximately to scale.)

Occultations of stars.

(7) *Tides.*

Observations of times of high or low tide on successive days.

Connection of period with moon's period.

Spring tides and neap tides.

Heights of tides; influence on development of sea- and river-ports.

(With advanced classes—calculation of tide-producing forces; explanation of two

tidal waves ; effect of tides on motion of earth and moon ; Darwin's tidal evolution theory.)

(8) *Time.*

The solar day ; the mean solar day ; Greenwich Mean Time ; summer time.

The sidereal day and sidereal time ; the transit instrument.

The Nautical Almanac.

The work of the Time Department of Greenwich Observatory ; the time ball.

Sundials, their erection, graduation, and correction by the equation of time.

Chronometers and their use in determining longitude.

Local time and standard or zone time ; the date line.

Wireless time signals.

(9) *The Planets.*

Working knowledge of complete solar system ; illustrations by working models and scale drawings, etc.

Orbits, periods, sizes, and satellites of the planets. How planets differ from stars.

Surface markings and characteristics of the individual planets. (Illustrated by photographs.)

(*Note.*—Sir John Herschel, in his "Outlines of Astronomy," gives an interesting illustration of the relative sizes and distances from the sun of the members of the solar system which is worth quoting here: "Choose any well-levelled field. On it place a globe 2 feet in diameter. This will represent the Sun. Mercury will be represented by a grain of mustard-seed on the circumference of a circle 164 feet in diameter for its orbit; Venus, a pea, on a circle of 284 feet in diameter; the Earth, also a pea, on a circle of 430 feet; Mars, a rather large pin's head, on a circle of 654 feet; the Asteroids, grains of sand, on orbits having a diameter of 1,000 to 1,200 feet; Jupiter, a moderate-sized orange, on a circle nearly half a mile across; Saturn, a small orange, on a circle of four-fifths of a mile; Uranus, a full-sized cherry or small plum, upon a circumference of a circle more than a mile in diameter; and, finally, Neptune, a good-sized plum, on a circle about 2½ miles in diameter."

It may be added that on this scale the nearest fixed star would be over 4,000 miles distant.)

These relative distances may be illustrated in another way by marking them, according to a convenient scale, on the wall of the school hall or of a corridor, or on the school playground.

PLAN

	A	B	C		D	E		F
			ft.	in.[1]		yrs.	mths.	
Mercury	36	100		1	4		3	3,030
Venus .	67	188		1·9	7		7½	7,700
Earth .	93	260		2·6	10	1	0	7,918
Mars .	141	395		4	16	1	10	4,230
					28			
Jupiter .	483	1,350	1	1	52	11·9 yrs.		86,500
Saturn .	886	2,500	2	1	100	29·5 "		73,000
Uranus	1,781	5,000	4	2	196	84 "		31,900
Neptune	2,792	7,800	6	6	388	165 "		34,800

A. Mean distance from sun. Millions of miles.
B. Years of train journey from sun at 40 miles per hour.
C. Relative distance from sun. Mercury = 1 inch.
D. Bode's number.
E. Time taken for one revolution.
F. Diameter, miles.
G. Diameter relative to earth's diameter.

[1] N.B.—On this scale the nearest star (other

(For the purposes of comparison the data brought together in the table on pages 108–9 may be of use to the teacher. Some of the items are from Young's "Manual of Astronomy.")

(10) *Visitors to the Solar System.*

Comets; early superstitions; nature and dimensions; orbits; famous comets; photographs.

Meteors and shooting stars; famous showers.

ETS

G	H	I	J	K	L	M	N
						days. hrs.	
0·38	23 to 25	1/21	0·4	0·8	4·7	88 0	—
0·97	21·9	4/5	0·8	0·9	4·9	225 0	—
1·00	18·5	1	1·0	1·0	5·5	24	1
0·53	15·0	1/9	0·4	0·7	3·9	$24\frac{1}{2}$	2
10·92	8·1	318	2·6	0·2	1·3	10	9
9·17	6·0	95	1·2	0·1	0·7	10	10
4·03	4·2	14·6	0·9	0·2	1·2	?	4
4·39	3·4	17	0·9	0·2	1·1	?	1

H. Velocity in orbit. Miles per second.
I. Mass, relative to earth.
J. Surface gravity, relative to earth
K. Density, relative to earth.
L. Density. Water = 1.
M. Time for rotation on axis.
N. Satellites.

than the sun) would be distant about 4 miles.

(11) *The Stars.*

Illustrations to give some appreciation of their enormous distance from the earth.

Numbers visible to naked eye, telescope photography.

Plotting of star positions and maps; star catalogues.

Famous constellations and stars.

Magnitude.

Variable stars; double and multiple stars; new stars.

The Milky Way.

Nature and composition.

(12) *Nebulæ.*

Famous nebulæ.

Nature; size; theories.

Running concurrently with the above course there should be observational and practical work, suggestions for which are given below. If possible (for London schools it is possible), visits should be made to the astronomical section of the Science Museum in South Kensington and to the Greenwich Observatory.

The teacher need not attempt with his class the whole of the practical work suggested here. Some of it may be already included in a course of practical geography or of practical mathematics; and a few of the exercises are too difficult for the ordinary elementary school. The teacher should choose

what appeals to him and will be of value to the course he proposes to teach.

(1) *Introductory.*

(*a*) Angles ; use of protractor.

(*b*) Drawing to scale.

(*c*) Measurement of angles in horizontal plane.

(*d*) Measurement of angles in vertical plane.

(*e*) Make a simple theodolite to measure angles in horizontal and vertical planes.

(*f*) Examples in heights and distances.

Application of these methods to understand how the distance to the moon is measured.

(*g*) Establish the principle that an object which subtends an angle of 1° is distant approximately 57 times its own size.

Example : Moon's diameter subtends an angle of about $\frac{1}{2}^\circ$.

$\therefore$ Moon's diameter $= \frac{1}{2}$ of $\frac{1}{57}$ of its distance from earth.

$= \frac{1}{114}$ of 239,000 miles.

$=$ 2,000 miles, approximately.

(2) *The Earth.*

(*a*) Idea of earth floating in space.

Meaning of (i) horizontal and (ii) vertical at different places on the earth's surface.

How these are determined, e.g. plumb-line and water or mercury surface.

(*b*) Longitude and latitude as angular measures.

(*c*) Demonstration of earth's daily rotation.

(i) Tube pointed to sun or star; image soon crosses field of view.

(ii) Photographs of stars in neighbourhood of Pole Star with fixed camera and lens, exposure being of several hours' duration.

(iii) Hourly observations of a particular star, using theodolite.

(iv) Foucault's pendulum.

(*d*) Demonstration of earth's annual motion round sun, by making simple star charts at, say, monthly or quarterly intervals throughout the year.

(*e*) Construct model of earth-moon-sun system with plane of moon's orbit making an angle of 5° with plane of earth's orbit, to illustrate solar and lunar eclipses and phases of the moon.

(*f*) The points of the compass.

How to find these from the sun at noon, or from the sun at any hour of the day with the aid of a watch, or by the stars at night.

(3) *Solar Observations.*

(*a*) Variation in the length of day (as opposed to night) throughout the year:

(i) By observing approximate time of sunrise and sunset, or, more accurately,

(ii) by observing the sun's altitude at noon daily or at weekly intervals throughout the year by means of a simple theodolite or a shadow-board.

These observations should be plotted to give a diagram which will show the longest and shortest days and the equinoxes. (See remark on this subject in connection with Weather Study, page 95.)

Where the altitude of the sun at noon is measured in angular measure, or is obtained by calculation from shadow-lengths, the meaning of this angle should be explained with the aid of a globe to show the relation between the sun and the earth at the time the observation is made.

(*b*) Laying out a meridian.

In all schools where observational work in geography or astronomy is done, there should be marked on the playground or elsewhere the meridian of the place. The meridian may be laid out in any of the following ways:

(i) Use a good magnetic compass. This will give the magnetic north and south line, which must then be corrected for declination. (At present the magnetic meridian at London points about 14° to the west of the true meridian.)

(ii) Use the shadow-board and determine the position of the shadow when it is shortest. This gives the meridian. (The position of the minimum length of shadow of a vertical stick is best determined by taking two positions of the shadow, about an hour before and after noon, which are equal and bisecting the angle between these.)

(iii) Mark the position of the shadow of a tall vertical stick or plumb-line exactly at "local noon." (The Greenwich Mean Time of "local noon" is obtained by correcting for longitude and for the "equation

of time." No correction for longitude is, of course, necessary in or near London. A correction of four minutes is to be added to, or subtracted from, Greenwich Mean Time for each degree of longitude the school is west or east of the Greenwich meridian. The "equation of time" corrections are given in the table on page 116. From this it will be seen that no appreciable correction is necessary about the middle of April, about the middle of June, at the beginning of September, and on December 24 and 25.)

(4) *The Determination of Time.*

(i) Local noon. Having laid out a meridian, it will be easy to find "local noon." This occurs when the shadow of a vertical stick coincides with the meridian. From this the correct Greenwich Mean Time is deduced by correcting for longitude and for "equation of time."

(ii) Construction and use of a simple horizontal sundial, and how to correct readings to give Greenwich Mean Time.

(iii) Construction and use of a simple vertical dial for a south wall, and how to

correct readings to give Greenwich Mean Time.

EQUATION OF TIME.

The following table shows the number of minutes (to the nearest ıole minute) to be added to, or subtracted from, sundial time to /e Greenwich Mean Time.

Prefix A denotes "add." S denotes "subtract."

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	A. 4	A. 14	A. 13	A. 4	S. 3	S. 2	A. 4	A. 6	A. 0	S. 10	S. 16	S. 11
2	"	"	A. 12	"	"	"	"	"	S. 0	S. 11	"	"
3	"	"	"	A. 3	"	"	"	"	S. 1	"	"	S. 10
4	A. 5	"	"	"	"	"	"	"	"	"	"	"
5	"	"	"	"	"	"	"	"	"	"	"	S. 9
6	A. 6	"	A. 11	"	"	"	"	"	S. 2	S. 12	"	"
7	"	"	"	A. 2	S. 4	S. 1	A. 5	"	"	"	"	"
8	A. 7	"	"	"	"	"	"	"	"	"	"	S. 8
9	"	"	"	"	"	"	"	A. 5	S. 3	S. 13	"	"
10	A. 8	"	"	A. 1	"	"	"	"	"	"	"	S. 7
11	"	"	A. 10	"	"	"	"	"	"	"	"	"
12	"	"	"	"	"	S. 0	"	"	S. 4	"	"	S. 6
13	A. 9	"	"	"	"	"	"	"	"	S. 14	"	"
14	"	"	A. 9	A. 0	"	"	A. 6	"	"	"	"	S. 5
15	"	"	"	"	"	A. 0	"	A. 4	S. 5	"	S. 15	"
16	A. 10	"	"	S. 0	"	"	"	"	"	"	"	S. 4
17	"	"	"	"	"	A. 1	"	"	"	"	"	"
18	"	"	A. 8	S. 1	"	"	"	"	S. 6	S. 15	"	S. 3
19	A. 11	"	"	"	"	"	"	"	"	"	"	"
20	"	"	"	"	"	"	"	A. 3	"	"	S. 14	S. 2
21	"	"	A. 7	"	"	"	"	"	S. 7	"	"	"
22	A. 12	"	"	"	"	A. 2	"	"	"	"	"	S. 1
23	"	"	"	S. 2	S. 3	"	"	"	"	S. 16	"	"
24	"	A. 13	A. 6	"	"	"	"	A. 2	S. 8	"	S. 13	S. 0
25	"	"	"	"	"	"	"	"	"	"	"	A. 0
26	A. 13	"	"	"	"	"	"	"	S. 9	"	"	A. 1
27	"	"	"	"	"	A. 3	"	"	"	"	S. 12	"
28	"	"	A. 5	S. 3	"	"	"	A. 1	"	"	"	A. 2
29	"	"	"	"	"	"	"	"	S. 10	"	"	"
30	"		"	"	"	"	"	"	"	"	S. 11	A. 3
31	A. 14		A. 4		"		"	A. 0		"		"

(iv) Observe the time of transit of a planet. The exact Greenwich Mean Time when this should occur at Greenwich is given in the Nautical Almanac and in

Whitaker's Almanack, and so the clock can be corrected.

(This is a useful exercise, as it illustrates the method by which the astronomer checks his clocks by means of the stars. He finds the error of his sidereal clock by comparing the time it shows when a certain star crosses the meridian compared with the true time at which the star should cross as obtained by calculation and given in the Nautical Almanac. Knowing correct sidereal time, he can translate this into Greenwich Mean Time.)

Sufficiently accurate observations for our purpose can be obtained by using a long tube with cross-threads at each end, the tube's axis coinciding with the meridian, or by using two plumb-lines suspended in the meridian several feet apart. When the planet and these two threads coincide, the planet is in the meridian.

(v) Observe the time of transit of the moon. This may be done by the methods described in (iv), and is particularly suitable for school work, as the moon on certain days of the month is visible during the day or early evening. The Greenwich

Mean Time at which the moon "souths" (i.e. crosses the meridian) is given in Whitaker's Almanack as well as in the Nautical Almanac.

(5) *Determination of Longitude.*

For this we have merely to find the difference between (i) the time when the sun crosses the local meridian and (ii) the time when the sun crosses the Greenwich meridian.

(i) occurs when the sun is at its highest altitude (and this is determined by theodolite, sextant, or shadow-board).

(ii) is obtained from the chronometer (or by wireless) corrected for "equation of time."

Each hour of difference between these represents 15° of longitude.

(6) *Determination of Latitude.*

(i) By measuring the altitude of the Pole Star. This is an easy observation for schools and can be done fairly accurately with a school-made theodolite. A diagram or globe will show why this angle gives the latitude.

(ii) By measuring the altitude of the sun at noon. A diagram will show that the

latitude is the complement of this angle corrected by the amount the sun is above or below the equator according to the season of the year. The amount of this correction (the sun's "declination") will be found for each day of the year in Whitaker's Almanack or in the Nautical Almanac. On March 22 and September 22 this correction is zero, for the sun is then over the equator. On June 22 and December 22 the correction reaches its maximum of $23\frac{1}{2}^\circ$ above and below the equator respectively.

(7) *Lunar Observations.*

(*a*) Observe the moon's phases throughout the month, and study these with the aid of the model of the sun-earth-moon system to show the relative positions of each.

(*b*) Observe the times when the moon crosses the meridian, or passes a particular star, on successive days or nights.

The observed difference of these times should, where possible, be compared with the difference of times of high or low tide on successive days.

(*c*) Eclipses. Observations of lunar and solar eclipses, these phenomena being further

illustrated by models to show relative positions of sun, moon, and earth at the time of the eclipse.

During solar eclipses, observations by means of images should be made of the proportion of the sun's disc obscured and, corresponding with these, there should be made observations of sun and shade temperatures. If these are reproduced in graphical form, there will be seen a striking and interesting fall in temperature as the sun's disc becomes more and more obscured.

(8) *Star Observations.*

(*a*) Making star charts.

Even if these include little more than the brightest stars and best known constellations (for example, Great Bear, Little Bear, Cassiopaeia, Vega, Capella, and Orion), the exercise is instructive.

These maps may be used to show (i) the diurnal motion of the earth and (ii) the annual revolution of the earth round the sun.

The teacher should try to give his pupils some idea of the depths of space and the position of the earth and solar system in relation to the stars we see in our skies.

(*b*) Star transits.

By means of a simple theodolite in a fixed position, approximating to the meridian, or by two vertical plumb-lines in the meridian some feet apart, observe, on successive nights, the times at which the same bright star passes the line of sight. A series of these observations extending over a week will establish a reasonably correct average result to show that the sidereal day is four minutes less in duration than the solar day.

(9) *Observations of Planets.*

(*a*) Observe and plot the path of a planet among the stars by taking observations of its position relative to neighbouring stars once or twice a week for several weeks.

(*b*) Transits of planets.

(i) Daily difference in time of transit.

(ii) Determination of Greenwich Mean Time (as explained in section (4) (iv), page 116).

Note.—In the foregoing, reference to Greenwich Mean Time has frequently been made. Care must be taken during the summer months to make the correction necessitated by the use of "Summer Time."

CHAPTER XI

PHYSICS AND CHEMISTRY

ASTRONOMY has been discussed in greater detail than any of the other subjects already treated or still to be discussed, and this may give the impression that I regard it as the most important of them. This is not so; I regard it merely as a subject which is entitled to some consideration in the science curriculum of schools, and I have given fairly full suggestions for the school treatment of it because the subject so far has been neglected as a school study and I wish to show what may be attempted in both elementary and secondary schools.

Physics and chemistry have received, and continue to receive, the most attention of all the science subjects taught in boys' secondary schools. In fact, in many boys' schools the science teaching is confined entirely to certain sections of physics and chemistry. This is true also of central

schools and of ordinary elementary schools after the nature-study course has been completed. That physics and chemistry should form practically the only science subjects taught to boys after the age of about twelve years is not alarming to me, although I have been advocating a widening of the scope of school science teaching. But what is disturbing is the fact that much of this teaching of physics and chemistry is of far too restricted a nature and is not, in the full sense of their meanings, physics and chemistry at all, but only sections of these subjects. I believe that physics and chemistry should rightly claim first place in the post nature-study science course because they play a very important part in most of the other natural sciences, and because their range, if liberally interpreted, covers so many of the things man meets with in everyday life. I hope, therefore, that every boy and every girl will receive some instruction in physics and chemistry, even if it be only sufficient to explain the processes and principles involved in the courses already outlined. And where the science curriculum of the school already includes the subjects

of physics and chemistry, or where it is proposed to introduce them, I hope the teacher will see that he does not confine his teaching to one or two sections of these subjects, and that in all his lessons he endeavours to introduce illustrations and applications from all fields of science and thus help to broaden and humanise the subject.

In earlier chapters we have considered how this may be done, and in one or two instances illustrations drawn from the teaching of physics have been used. Generally speaking, and this applies to all schools—elementary, central, and secondary—physics is not made to cover all the sections which it properly embraces. A course in physics should cover the study of the properties of matter, mechanics and hydrostatics, heat, light, sound, magnetism, and electricity. And it is hoped that the teacher, having decided to teach physics, will include in his course the most important topics in each of these sections. Too often is the physics course confined to the study of one or two of these sections. These, particularly in secondary schools, are studied intensively, and the pupils are apt to obtain a wrong

impression of the importance of them, and to find themselves in the unfortunate position of being fairly expert in the performance of certain laboratory experiments and of possessing a knowledge of certain academic facts relating to, say, heat or to electricity, while they are ignorant of the most fundamental principles of, say, sound or light. It may be necessary, for reasons beyond the control of the teacher, to study in more detail certain parts of physics and chemistry, and in the case of pupils in the senior forms of secondary and similar schools this may be desirable, but this should not be done to the complete exclusion of the other parts not so studied. The course, in such cases, should consist of a general one first in which, within the limits of the time available, are included the topics of most importance chosen from the complete range covered by physics and chemistry, and this may then be followed by a more intensive course dealing with the special sections or aspects which it is necessary to study on more specialised lines for some particular purpose.

In choosing from the various sections into which physics and chemistry are usually

divided what are the most important and most fundamental topics which should be discussed, the teacher should keep before him the aim of good science teaching, as discussed in an earlier chapter; and he should remember that only a small percentage of his pupils will continue their science studies in higher institutions. He should not, therefore, make his science course, as is too often the case, one suited to the needs of the few. The course should be complete in itself and cover the whole field of physics and chemistry. The number of topics discussed in each section will depend upon the time available each week and on the number of years the course will last; but knowing these limits of time, the teacher must so arrange the course that in the time available he shall deal with the most important and the most fundamental principles and applications of mechanics, hydrostatics, heat, sound, light, magnetism, electricity, and chemistry.

I do not propose to discuss in detail what a course of this nature should include. There are many excellent text-books which deal with each of these sections separately,

and the teacher must decide upon the topics he proposes to introduce from each. It may be a help to him in this process of choice and rejection to try to keep in the background the course of science which he himself received at the secondary school, university, training college, or elsewhere, to remember that his pupils will not all become expert or professional physicists or chemists, and to think of what will be, and what he would like to be, the attitude towards science of his pupils five or ten years after they have left the school. For convenience it may be desirable to break up the course into its conventional sections, but the boundaries should not be stressed; and, wherever possible, illustrations from different sections, and indeed from other sciences, should be given and discussed. Generalisations demand special attention, and certain important topics (for example, gravitation) which are not commonly found in existing school courses, probably because they do not easily lend themselves to measurement, should be included and discussed, even if no experimental work connected with them is done.

Even in an ordinary elementary school a fundamental idea like gravitation need not be neglected ; it can be explained in simple terms, and surely deserves more consideration than the much-discussed topics of density and specific gravity. The subject affords an opportunity for introducing some account of the work of Galileo on falling bodies and the pendulum, and of Newton in physics and astronomy. Energy and the principle of the conservation of energy are of so far-reaching importance that they should not be omitted from any physics course. Surface tension and diffusion experiments are frequently included, but it is not so common to find that the part these play in plant physiology and in biology is considered. The barometer forms an important topic, and if treated historically will prove an extremely interesting subject. Mechanics should include a knowledge of simple machines (levers, pulleys, screws, gears, etc.) and mechanical appliances which make man's work easier.

In former chapters occasional reference has been made to heat in connection with different subjects suggested for study. Heat

always proves an interesting and useful school study for both boys and girls. There are certain physical constants which can be measured easily, and probably because of this too much emphasis has been given to those parts of heat, such as specific heats, latent heats, coefficients of expansion, etc., which afford scope for exact measurement. Such exercises are useful, and where the facilities for them exist one does not wish to see them discontinued, provided the pupils realise what these properties they can measure so well mean. Unfortunately it is possible for pupils to ascertain experimentally with reasonable correctness the "latent heat of steam" or the specific heat of lead and yet be extremely vague as to what these terms mean, or in what connection they are met with in everyday life. The heat course should include the important principle of the equivalence between heat and work; the historical development of this, introducing the work of Rumford, Davy, Joule, etc., is extremely interesting and fascinating. And no heat course should be regarded as complete if it does not include some simple treatment of

the steam-engine (locomotive and marine), the turbine, and the internal combustion engine (motor-car, aeroplane, etc.).

Sound and light are not so frequently included in school courses as heat. Yet they play an important part in our everyday life, and they form attractive studies, if properly treated, for pupils of all ages. It is easy to show that sound requires some medium (for example, air, water, or solid) in which to travel; that it travels in these media with different velocities, and that these velocities can be accurately determined. Vibration and resonance should be studied by means of stretched strings, wires, and tuning-forks, and the course should include the study of the human ear, the gramophone, violin, pianoforte, pipe-organ, etc. Light offers opportunities for simple experimental work without elaborate apparatus. It can be shown that light travels in straight lines and that its velocity is very great. The methods of measuring this enormous velocity will win the pupils' admiration for the achievements of science, and this will be further aroused if wave-lengths and their sizes are discussed. It should be shown

that light differs from sound in being able to travel across a vacuum, and the simple laws of reflection and refraction should be explained. Lenses, prisms, mirrors, the human eye, the camera, spectacles, the telescope, the microscope, the periscope, the projection lantern, the spectroscope, etc., will all find a place in the syllabus. Simple colour work will prove fascinating, and if the subject is discussed, as it should be with older pupils, from the point of view of wave-lengths, some attempt should be made to show the unity and wide range of æther vibrations outside the limits of the visible spectrum, ranging from gamma-rays, X-rays, ultra-violet rays, through the visible light rays from violet to red, infra-red, and heat rays, to the popularly known wireless waves. The amazing differences in the sizes of these waves and the wonderful devices used to detect their presence will interest the pupils and give them an appreciative respect and admiration for the patience and industry of the scientific workers in this field of activity.

The course in magnetism and electricity should not give undue prominence to static

electricity. For most pupils it should be sufficient to demonstrate what is meant by a conductor and an insulator, and proceed to current electricity and the many applications of this to everyday life. The electromagnet, invented a century ago by William Sturgeon, a poor shoemaker with little education, forms the basis of so much of our modern electrical apparatus and machinery (for example, the electric bell, the electric motor and dynamo, the magneto, the telephone and telegraphic instruments) that the teaching may well be developed around this. The generation of electricity on a large scale for lighting, for driving workshop machinery, and for railways and tramways should be studied, and, if possible, a visit should be made to a big generating station. The use of electricity for lighting and heating purposes in our homes is increasing, and it is therefore important that our pupils should have at least a simple working knowledge of the subject. A course of magnetism and electricity, including consideration of the numerous applications to industry and everyday life met with in the bell, the motor, the dynamo, the tele-

phone, the telegraph, wireless, lighting, heating, clocks, etc., is within the range of the ordinary elementary school, and in schools where such a course is given the work has proved valuable and successful. This course has the additional advantage of being possible, even with experimental work, in the ordinary class-room, and it also affords excellent opportunities for including with it the construction of working models, wireless receiving sets, and other pieces of electrical apparatus.

In the ordinary elementary schools chemistry should be treated very simply, and suggestions have already been made for introducing a small amount of chemistry in connection with the teaching of hygiene and domestic science. The study of air and water, whether included in a hygiene course or in a physics course or in a separate chemistry course for elementary schools, will embrace the study of oxygen, nitrogen, hydrogen, and carbon-dioxide. In the study of the nature and composition of other common things and of combustion there will be introduced a few other important elements like carbon, sulphur, sodium, and

the common metals. The pupils should learn how these metals are extracted from their ores, and about our large iron, steel, and other metal industries and manufactures. They should carry out experiments involving distillation, solution, crystallisation, the action of certain acids on common substances, and the making of coal-gas and of soap. The simple study of mixtures and chemical compounds will lead, in the case of the older pupils, to a knowledge of the laws of chemical combination. Pupils in central schools and secondary schools should know the full significance of these laws, and their knowledge of atoms and molecules should be extended (even if only in a popular and elementary way) to include the modern views of the constitution of matter. If the course forms part of a larger scheme of science, as it should, up to at least the age of fifteen or sixteen years, there will be little time for anything more than the above, but in the senior forms of secondary schools, where chemistry is studied as a separate subject and possibly for examination purposes, a much more technical course will be followed. This applies also to certain portions of physics, and as, at the

stage where this specialisation would be introduced, there would exist a specialist teacher of the subject and, I hope, adequate facilities for experimental work, the question of the syllabus may safely be left in his hands.

Throughout the teaching of physics and chemistry opportunities will arise for impressing upon the pupil the wonderful law and order which exist in physical nature. Thus, a pure metal has a definite density, specific heat, etc., and reacts in certain definite ways under certain conditions; these reactions and definite physical properties are sufficient to identify that metal. By the peculiar and distinctive behaviour of each chemical element we are able to detect the presence of any element wherever it exists, and in this way we know the constitution of terrestrial substances, of the sun and of certain stars. The sun rises day by day without failure. We can calculate the positions of planets, stars, etc., and tell when a comet will pay its next visit to our system, simply because we know the laws which govern their motions. A body falls to the ground to-day with a definite accelera-

tion ; if released under the same conditions to-morrow or the next day or next year it will fall with the same acceleration. It is by contemplating such facts as these that the pupils will arrive at a notion of the universal prevalence of law in physical nature.

CHAPTER XII

BOTANY, BIOLOGY, AND GEOLOGY

OF the list of subjects set out in the table on page 71, one or more of which it is suggested should be studied in our Groups II and III, there remain to be considered Botany, Biology, and Geology. Certain topics already discussed in the sections dealing with Hygiene and Physiology, with Domestic Science, with Weather Study, and with Nature Study would legitimately come within the scope of suggestions bearing on Botany, Biology, and Geology, and some teachers, particularly those in the ordinary elementary schools, may feel that in their treatment of any of the first-named subjects they have included as much of the subject-matter of the last-named three subjects as they think desirable or suitable for their pupils. But in central and secondary schools there should be opportunity for definite science courses which may legitimately be

dignified by the title of Botany, Biology, or Geology.

Of these three subjects Botany is the most popular, but its popularity is confined to girls' schools. In these it takes the position corresponding with that of physics and chemistry in boys' schools. Several reasons for this can be adduced; in the first place, girls have a natural interest in flowers and plants (just as boys have in mechanical things), and therefore the subject appeals to them; secondly, botany does not rank as a mathematical science and consequently its study can be pursued without any advanced knowledge of mathematics. While it is probably desirable that a biological science should take the place of first importance in girls' schools and physics and chemistry in boys' schools, it is unfortunate that the division is so complete as it is to-day: physical science is neglected in girls' schools and biological science is neglected in boys' schools. The science course of each would benefit by the introduction of some of the teaching now given in the other.

This is easily possible in the case of the girls' schools, and in some schools it is

already being done, for the introduction in recent years, in increasing amount, of the study of the physiology of plant life as part of the botany course demands a knowledge of certain important parts of physics and chemistry, so that even if the latter do not appear as separate studies in the science course, they will not be entirely neglected if the botany course includes, as it should do, physiological processes in plants. This is a fascinating study and one which is of interest and value to pupils of both sexes. It lends itself, also, to experimental work of a different nature from that associated with the descriptive study of botany.

The neglect of biological science in boys' schools may be remedied in two ways: by the introduction of a definite course, even if a short one, on the fundamental ideas and facts of biology, or by introducing some of these as illustrations of chemical and physical laws and phenomena. For example, lessons on osmosis, diffusion, capillarity, oxygen, carbon-dioxide, starch, carbon, etc., included in the physics and chemistry course can be well illustrated from biological examples. This is in keeping with the plea

advocated throughout this book that illustrations and applications should be chosen from all branches of science. The short course on biology is the better method of remedying the defect, and if the demands of some other subject do not render it impracticable, it should be included. It is an important subject and deserves a place in an education which prepares for life. If examination requirements or other unavoidable circumstances prevent it from receiving reasonable consideration as a part of the instruction, books of a readable nature on general biology should be included in the science library and the pupils encouraged to read them in their private time. This will ensure that the subject is not, at least, completely neglected. Books of this nature are included in the Appendix (page 164).

The details of a botany scheme need not be given here. As a rule the subject is well taught. The extent to which technical names and the strict classification of plants are introduced will depend on the age of the pupils; there should be no need for these in the ordinary elementary school. The physiology of plant life, as already

stated, is important and should have a place in schemes for all schools, and processes should be illustrated by experiments. Field work should be encouraged, and younger pupils should use a pocket lens; microscopic work, the cutting and study of sections, the study of cell structure, adaptation to environment, evolution, and so forth should be reserved for older pupils.

Biology is a bigger subject than Botany; it includes the study of plant life, of animal and of human life. In other words, it embraces the sciences of Botany, Zoology, Hygiene, and Physiology. Because of its wide range and practical value it deserves a place in the school curriculum. What we have been discussing under the name of "Nature Study" includes many of the general and elementary facts and principles of biology. Beyond the "nature-study stage" there is much material which can be woven into an admirable course in elementary biology suitable for secondary and central school pupils, particularly girls. For much of this, elaborate and expensive apparatus is not necessary; powerful microscopes may be necessary in the advanced stages,

but these are not essential in the early stages; a lantern and suitable slides will prove of great value both in the elementary and advanced stages. The extent to which the study is prosecuted will depend upon the time at the teacher's disposal and on the age and previous scientific training of the pupils. The course should aim at giving some idea of the main forms of life, of the fundamental processes involved, and of the unity and interdependence which exist among the elements of the organic world. It should include some study of the forms and classification of plant and animal life; structure and living processes; bacteria and other micro-organisms; the germ-theory of disease; the laws of health; the theory of organic evolution; adaptation, selection, heredity, etc. The constituents of living matter and the fundamental processes (respiration, nutrition, circulation, etc.) involved in life will require some previous or collateral teaching in physics and chemistry. And by no means the least interesting part of a biological course will be the study of the remarkable achievements of men of science like Harvey, Linnæus,

Lamarck, Jenner, Koch, Darwin, Mendel, Pasteur, Fabre, Wallace, Huxley, and Lister, and of the contribution biology has made, and continues to make, towards the solution of social problems.

Geology may, in some respects, be regarded as the complement of Biology; it deals with the inorganic world: with inanimate nature, while Biology deals with the organic world: with animate nature. As a science it has not had an important place in school study. Beyond the simplest facts about the formation and structure of the earth's crust, and of the agencies at work upon and in it, which are usually included in physical geography lessons, there is not much which can be properly dealt with in the ordinary elementary school; but for secondary and central schools the subject is a very suitable and important one. A knowledge of it broadens one's outlook and enriches one's treasure-store of knowledge from which intellectual enjoyment is derived. Field work, including the study of local formations, rocks, etc., should play a large part in the scheme, and visits should be made to selected regions where particular phenomena can be studied. The

making of geological maps and models affords opportunities for instructive and valuable handwork, and collections of fossils, rocks, and minerals should be made. The course should aim at giving a complete and accurate story of the history of our planet, of the present conditions obtaining upon it, and of the changes which have taken place with time. There should be included the study of rocks of different kinds; movements of the earth's crust; volcanoes; geysers; the action of sea, rain, rivers, frost, and glaciers; deposits; the work of famous geologists; and the economic aspect of the study bearing on agriculture, water-supply, and the sources (and where necessary the purification) for industrial purposes of coal, oil, iron, tin, lead, copper, and other metals.

Group IV of the table on page 71 includes pupils and students over sixteen years of age who have already had a course of science in Group III, and desire, because of interest in the subject, or because of requirements with a view to future employment, to carry their studies further. The group would include pupils in secondary

schools taking an "advanced course" in science and students in technical colleges and universities. The teaching in these cases should be on intensive and more highly specialised lines, and should include a rigorous and systematic course of experiments involving exact quantitative work.

CHAPTER XIII

THE TEACHER

THE problem of the teaching of science in schools is not simply one of what should be taught and how it should be done. There are also the problems of the time-allowance and the teacher. As regards the allowance of time to be given to science in the time-table, I have no desire to press unduly the claims of science to a larger proportion of the school-time than it deserves in fair competition with the many other subjects which rightly have a place in the school curriculum. During the "nature-study stage," i.e. from about the age of eight to about the age of twelve years, there should be at least two lessons per week of about half an hour each. Throughout the remainder of the pupil's school-life in the ordinary elementary school he should have at least two lessons of from forty minutes to an hour each. In central and secondary schools

where special provision for science teaching usually exists, a minimum of three hours per week should be given. Pupils taking advanced courses in science, or studying the subject intensively for some special purpose, will, of course, require much more than the minimum here stated.

The problem of the teacher is of most importance, for the success or failure of the course rests mainly with him. He may be given an ideal syllabus to work from, he may have well-equipped laboratories and an ample time-allowance for his lessons, but unless he adds to these a personal enthusiasm for, and love of, his work and, of course, a reasonable ability in teaching, his syllabus and equipment will be of little avail. The keen, well-informed teacher with the right aims will succeed in spite of difficulties of equipment and similar handicaps. For this reason it is essential that the teaching should be entrusted to those who love the subject and believe in its value. Even in the ordinary elementary school specialisation should be adopted, the science instruction being kept in the hands of one or two teachers with special aptitude and

desire for it. In schools giving higher instruction than the ordinary elementary school, specialisation of this nature is the rule.

Our need now is the supply of suitable teachers of science for our schools, and this brings us right to the root of the matter, for if any distinct progress in a particular direction is necessary, it is important that there should be a supply of teachers able to give effect to this. The teachers of our public elementary schools are recruited from the training colleges of the country, and hence, so far as the elementary schools are concerned, we must look to these training colleges to produce the teachers able to do the work. But, unfortunately, many of the training colleges are not doing so. Young teachers leave the colleges in large numbers each year knowing very little science; others may have studied science during their college course, but their studies have been restricted to a narrow field (for instance, many women have studied no science other than botany, and this often has been of a technical nature). And, further, very few even of those who have taken a college

course of science have received any direct instruction in the methods of teaching science, so that they enter the schools and begin teaching science without having had any opportunity to learn or discuss the technique of their work.

The remedy for the future lies, therefore, with the training colleges. These should provide two essential contributions towards a solution of the problem:

(i) A course of general science on a broad and liberal basis for students who will enter the elementary-school service. This course would give teachers a reliable introduction to the physical and biological sciences suitable for the requirements of the ordinary elementary school; and this introduction would form a foundation upon which they could build later if specialisation in any particular branch were desirable.

(ii) A short course on the methods of teaching science, with opportunities to observe and practise methods in schools where the work is well done.

In the case of students who have taken, or are taking, a university degree course in science, the course on method suggested

in (ii) above should form an indispensable part of their professional training in college, as these students are likely to undertake some science teaching in the future. And as a university degree in science may be obtained after study in a restricted field of science, it is desirable that intending science teachers should supplement their degree course by a short post-graduate course of reading or study in one or more of the sciences not included in their degree course. For example, a science graduate in physics or chemistry should, if he means to become a teacher of science, have some knowledge of a biological science, and *vice versa*.

The training colleges can help very considerably in giving their students the proper outlook on science and in seeing that there is an adequate supply of teachers qualified to teach the subject in the best ways. But there are, particularly in our secondary schools, many teachers who have received no professional college training as teachers, and such training has not been, and is not, regarded as an indispensable qualification for appointment to these schools, so that in

such cases teachers may continue to be appointed who have made no special study of the problem of teaching science. Under present conditions it may not be possible to insist on all teachers in grant-aided secondary schools being trained, but I hope this will be practicable in the not too distant future. In the meantime, it should be possible to arrange, in certain centres, vacation or evening courses in which the technique and methods of teaching science could be discussed.

Finally, science ~~teachers, in~~ common with all other teachers, require the stimulus of the "refresher course"; their enthusiasm needs to be revived occasionally, and they should have some intellectual food and recreation to renew their youth and vigour. These can be supplied by well-conducted and inspiring courses by eminent and successful teachers and leaders in the scientific world. Certain local education authorities arrange lectures and courses of this type for their teachers, and these have proved helpful. The Board of Education, too, arrange occasional holiday courses with this end in view. These keep the teacher up to date,

and the temporary change from teacher to student often acts as a valuable intellectual tonic. In addition to the opportunities these courses should offer for academic study and for the discussion of pedagogic methods, there should be afforded opportunities for instruction in laboratory management and in the many arts, such as glass-blowing, soldering, metal and wood work, so useful to the science teacher.

Other possible ways of keeping in touch with modern developments and movements include visits to schools and colleges where special features of science are successfully taught, membership of a good science association or society, and membership of a library containing important books and publications in all branches of science.

Earlier and brief reference has been made to the influence on the secondary schools of external examinations. It is the duty of these schools to discharge their obligation to their pupils to prepare them for examinations which have to be passed as a condition of entrance to a university or to certain professions. The requirements of such examinations cannot, therefore, be ignored,

and it is accordingly important for the universities and all examination bodies to realise the extent to which their syllabuses influence the work of the schools and to satisfy themselves that this influence is in the right direction and in accordance with modern requirements.

In certain sections of this book I have endeavoured to show what these modern requirements appear to me to be. Briefly stated, they amount to a widening of the scope of science teaching in order to give all pupils an intelligent and appreciative interest in nature and in physical and mechanical laws and phenomena, together with the applications of these met with in our daily life and reading. The human, historical, and literary aspects of the subject should also be developed, for these have a cultural and humanising influence which has not yet been so fully recognised in science teaching as in other school subjects. This broadening of the course may mean a curtailment in the amount of exact measurement and experiment performed by the pupils, but it is not intended that the value of such practical work should be depreciated ;

any possible loss due to a diminution in the number of such laboratory exercises will be more than compensated by the gain of a wider and more lasting appeal.

APPENDIX I

BOOKS FOR THE SCIENCE LIBRARY

THE school library has undoubtedly played an important part in the improvement which has taken place in late years in the teaching of English. It can play a similar part in the teaching of science. In certain elementary schools I have seen attempted the experiment of having a science library of interesting, instructive, and well-written books on science subjects. This has proved a splendid aid to the teacher in his work, and has given the pupils a wide knowledge of scientific matters of all kinds, and has engendered an interest which is likely to be retained after the pupils leave school. I can, therefore, strongly recommend the practice; and in order to assist teachers in their choice of books suitable for the school science library, I append lists which have been prepared from personal knowledge of the books. (London teachers will find most of these books on the Council's Requisition List.) Ordinary text-books are not included, with the exception of a few of recent issue which deal with general science, or which are written in a manner that makes them suitable for library purposes.

* Books marked thus are not suitable for pupils in ordinary elementary schools, but may be of interest to teachers in these schools. They are also suitable for secondary-school pupils.

† Books marked thus are specially suitable for young children of ages nine to twelve years.

Books of General Scientific Interest

*The Outline of Science. 2 vols. Thomson. (Waverley.)

Elements of General Science. Caldwell and Eikenberry. (Ginn.)

General Science. Elhuff. (Harrap.)

*An Introduction to the Study of Science. Smith and Jewett. (Macmillan.)

General Elementary Science. Willings. (Blackie.)

Science of Everyday Life. Buskirk and Smith. (Constable.)

Common Science. Washburn. (Bell.)

General Science. Thompson and Leslie. (Cassell.)

Science for Boys and Girls. Nichols. (Lippincott.)

Wonders of Physical Science. Fournier. (Macmillan.)

Wonders of Scientific Discovery. Gibson. (Seeley.)

The Romance of Scientific Discovery. Gibson. (Seeley.)

*Stories of Scientific Discovery. Hammond. (Cambridge Press.)

A School History of Science. Cochrane. (Arnold.)
Scientific Ideas of To-day. Gibson. (Seeley.)
A History of the Earth from Star-dust to Man. Finnemore. (Longmans.)
The Romance of Modern Invention. Williams. (Seeley.)
The Romance of Modern Engineering. Williams. (Seeley.)
The Romance of Submarine Engineering. Corbin. (Seeley.)
The Romance of Modern Locomotion. Williams. (Seeley.)
The Romance of Modern Mechanism. Williams. (Seeley.)
The Romance of Modern Manufacture. Gibson. (Seeley.)
The Romance of Modern Railways. Corbin. (Seeley.)
All About Railways. Hartnell. (Cassell.)
All About Engines. Cressy. (Cassell.)
The Story of the Railway. Campling and Nicholls. (Cassell.)
All About our British Railways. Jackson. (Jack.)
The Book of the Locomotive. Jackson. (Longmans.)
Railways for All. Gairns. (Ward Lock.)
Wonders of Transport. Hall. (Blackie.)
Engineering. Knox. (Jack.)
Conquests of Engineering. Hall. (Blackie.)

Victories of the Engineer. Williams. (Nelson.)
Engineering for Boys. Hawks. (Jack.)
The Age of Machinery. Horne. (Blackie.)
Engineering of To-day. Corbin. (Seeley.)
Mechanical Inventions of To-day. Corbin. (Seeley.)
Aircraft of To-day. Turner. (Seeley.)
Submarine Engineering of To-day. Domville-Fife. (Seeley.)
Submarine Warfare of To-day. Domville-Fife. (Seeley.)
Ships for All. Bowen. (Ward Lock.)
Spinning Tops. Perry. (S.P.C.K.)
How it is Made. Williams. (Nelson.)
How it Works. Williams. (Nelson.)
Things to Make. Williams. (Nelson.)
Thinking it Out. Williams. (Nelson.)
Some Wonders of Matter. Mercer. (S.P.C.K.)
*Atoms and Electrons. Sullivan. (Hodder & Stoughton.)
*The A.B.C. of Atoms. Russell. (Paul.)
*Soap Bubbles. Boys. (S.P.C.K.)
The Wonderful Century. Wallace. (Allen.)
The Romance of War Inventions. Corbin. (Seeley.)
*Discoveries and Inventions of the Twentieth Century. Cressy. (Routledge.)
*Masters of Science and Invention. Darrow. (Chapman.)
*Non-technical Chats on Iron and Steel. Spring. (Stokes.)

Days at the Works. Cooke. (Hodder & Stoughton.)

The Romance of Industry. Wood. (Cassell.)

The Romance of Inventions. Nicholls. (Cassell.)

Photography of To-day. Jones. (Seeley.)

Photography and its Mysteries. Gibson. (Seeley.)

*Discovery, or the Spirit and Service of Science. Gregory. (Macmillan.)

Outdoor School Work. Feasey. (Pitman.)

The Age of Power. Riley. (Sidgwick & Jackson.)

Triumph of Man. (Pitman.)

Time and Tide. Ball. (S.P.C.K.)

Story of a Tinder-box. Tidy. (S.P.C.K.)

Common Commodities and Industries. (Pitman.)

The series includes :

Boot and Shoe Industry.	Linen.
	Motor Industry.
Clays.	Oils.
Coal.	Paper.
Coal Tar.	Rubber.
Coffee.	Silk.
Copper.	Soap.
Cotton.	Sugar.
Glass.	Tea.
Gums.	Timber.
Iron and Steel.	Wheat.
Leather.	Wool.

†Rambles Among Our Industries. (Blackie.)

The series includes :

Airman and His Craft. Claxton.

Coal and the Miner. Claxton.
Cotton and the Spinner. Claxton.
In the Potteries. Claxton.
Iron and the Iron Worker. Claxton.
Leather and Bootmaking. Claxton.
Lime and Cement. Adams and Elliott.
Our Railways. Adams and Elliott.
Paper and Printing. Claxton.
Seaman and His Craft. Claxton.
Silk and the Silk Worker. Claxton.
Wool and the Weaver. Claxton.

†Oxford Industrial Readers. Cooke. (Oxford Press.) The series includes:
Day in an Ironworks.
Day with the Leather Workers.
Day in a Shipyard.
Visit to a Coalmine.
Visit to a Cotton Mill.
Visit to a Woollen Mill.

*Science from an Easy Chair. Lankester. (Methuen.)

*More Science from an Easy Chair. Lankester. (Methuen.)

*Secrets of Earth and Sea. Lankester. (Methuen.)

*A Little Book on Water Supply. Garnett. (Cambridge Press.)

Nature Study

Wonders of Plant Life. Bastin. (Cassell.)
The Romance of Plant Life. Elliott. (Seeley.)

*Cassell's Natural History. 6 vols. Duncan. (Cassell.)

*British Nature Book. Sedgwick. (Nelson.)

The Fairy Land of Living Things. Kearton. (Cassell.)

The Fairy Land of Science. Buckley. (Macmillan.)

Wild Nature's Ways. Kearton. (Cassell.)

British Natural History Studies. Westell. (R.T.S.)

Our Bird Friends. Westell. (R.T.S.)

*The Birds of the British Isles and their Eggs. 2 vols. Coward. (Warne.)

Birds Shown to the Children. Scott and Henderson. (Nelson.)

Bird Biographies. Pike. (Jarrolds.)

Birds and their Story. Lodge. (Sharp.)

British Birds. Hudson. (Longmans.)

Through Birdland Byways with Pen and Camera. Pike. (Jarrolds.)

*Birds of the Countryside. Finn. (Hutchinson.)

Birds one should Know. Wood. (Gay.)

The Romance of Bird Life. Lea. (Seeley.)

The Romance of the Seasons. Duncan. (Chapman.)

The Romance of Nature. Burton. (Methuen.)

The Boy's Own Nature Book. Westell. (R.T.S.)

*A Practical Guide to Nature Study. Crabtree. (Jarrolds.)

*Diversions of a Naturalist. Lankester. (Methuen.)

The Beauties of Nature. Avebury. (Methuen.)

The Children's World of Wonders. 3 vols. Sinel. (Caxton.)

Elements of Natural Science. Smith. (Arnold.)
Natural History Studies. Thomson. (Melrose.)
Every Boy's Book of British Natural History. Westell. (R.T.S.)
*Life of the Wayside and Woodland. Coward. (Warne.)
The Haunts of Life. Thomson. (Melrose.)
Nature all the Year Round. Thomson. (Pilgrim Press.)
Mountain and Moorland. Thomson. (S.P.C.K.)
Animal Ingenuity of To-day. Ealand. (Seeley.)
*Animal Life of the British Isles. Step. (Warne.)
Animal Life. Gamble. (Murray.)
Animal Life. Yates. (R.T.S.)
How Animals Work. Duncan. (Nelson.)
The Book of the Animal Kingdom. Westell. (Dent.)
The Romance of the Animal World. Selous. (Seeley.)
†Stories of Animal Life. Claxton. (Blackie.)
The Romance of Animal Arts and Crafts. Coupin and Lea. (Seeley.)
†Familiar Friends at Home. Cameron. (Blackie.)
Marvels of the Animal World. Berridge. (Thornton.)
Animal Heroes. Seton. (Constable.)
Wild Creatures of Garden and Hedgerow. Pitt. (Constable.)
Insects Shown to Children. Cooke. (Jack.)
†Stories of Insect Life. Claxton. (Blackie.)
Butterflies of the British Isles. South. (Warne.)

*Our Butterflies and Moths. Daglish. (Thornton.)
Everyday Doings of Insects. Cheesman. (Harrap.)
Marvels of Insect Life. Step. (Hutchinson.)
The Children's Life of the Bee. Maeterlinck. (Unwin.)
*British Insect Life. Step. (Werner Laurie.)
The Romance of Insect Life. Selous. (Seeley.)
The Romance of the Mighty Deep. Giberne. (Seeley.)
The Romance of the World's Fisheries. Wright. (Seeley.)
The Romance of the Microscope. Ealand. (Seeley.)
The Young People's Microscope Book. Sedgwick. (Sharp.)
Our Secret Friends and Foes. Frankland. (S.P.C.K.)
Rambles in the Woodlands. Claxton. (Blackie.)
The Wonder Book of Nature. Golding. (Ward Lock.)
The Wonder Book of Wonders. Golding. (Ward Lock.)
The Wonder Book of Why and What? Golding. (Ward Lock.)
The Country Day by Day. Wood. (Cassell.)
Garden and Playground Nature Study. Feasey. (Pitman.)
School Gardening. Hosking. (Tutorial Press.)
Eyes and No Eyes. Buckley. (Cassell.)
The Outdoor Year. Claxton. (Blackie.)
Water in Nature. Finch and Hawks. (Nelson.)

Sounding the Ocean of Air. Rotch. (S.P.C.K.)
Past at Our Doors. Skeat. (Macmillan.)
Tillers of the Ground. Newbigin. (Macmillan.)
The Seashore. Furneaux. (Longmans.)
†Seashore I Know. (Dent.)
†Wonders of Insect Life. Duncan. (Oxford Press.) The series includes:
Bees, Wasps, and Ants.
Butterflies and Moths.
Insect Life in Pond and Stream.
Some Curious Insects.
Spiders and Scorpions.
†Wonders of Plant Life. Duncan. (Oxford Press.) The series includes:
Land and Water Plants.
Plant Friends and Foes.
Plant Traps and Decoys.
Plants and their Children.
Some Curious Plants.
Story of the Plants.
†Wonders of the Sea. Duncan. (Oxford Press.)
Dwellers in the Rock Pools.
Wonders of the Shore.

BIOLOGY, HYGIENE, AND PHYSIOLOGY

(See also books on Nature Study given above.)

Biology for Beginners. Moon. (Harrap.)
Biology and Human Welfare. Peabody and Hunt. (Macmillan.)
The Biology of the Seasons. Thomson. (Melrose.)

*Everyday Biology. Thomson. Hodder & Stoughton.)
*Civic Biology. Hodge and Dawson. (Ginn.)
*The A.B.C. of Evolution. McCabe. (Watts.)
*Life and Evolution. Headley. (Duckworth.)
*Extinct Monsters and Creatures of Other Days. Hutchinson. (Chapman & Hall.)
*Darwinism and Human Life. Thomson. (Melrose.)
*Human Physiology. Furneaux. (Longmans.)
Medical Science of To-day. Evans. (Seeley.)

Botany

(See also list of Nature Study books above.)

First Studies of Plant Life. Atkinson. (Ginn.)
Aspects of Plant Life. Praeger. (S.P.C.K.)
Wayside Trees and How to Know Them. Robson. (Thornton.)
Botany of To-day. Elliott. (Seeley.)
Readable School Botany. Watson. (Bell.)
*The Wonder Book of Plant Life. Fabre. (Unwin.)

Geology

(See also books on Nature Study given above.)

Geology for Beginners. Watts. (Macmillan.)
Common Stones. Cole. (Melrose.)
Geology. Dwerryhouse. (Jack.)
The Making of the Earth. Gregory. (Williams & Norgate.)
Primer of Geology. Geikie. (Macmillan.)

The Romance of Modern Geology. Grew. (Seeley.)
Geology of To-day. Gregory. (Seeley.)

Astronomy

*The Story of the Heavens. Ball. (Cassell.)
*A Popular Guide to the Heavens. Ball. (Philip.)
Starland. Bell. (Cassell.)
A Voyage in Space. Turner. (S.P.C.K.)
Astronomy for Amateurs. Flammarion. (Nelson.)
*Popular Astronomy. Flammarion. (Chatto & Windus.)
This Wonderful Universe. Giberne. (S.P.C.K.)
How to Know the Stars. Gurney. (Newnes.)
The Children's Book of the Heavens. Proctor. (Harrap.)
Astronomy of To-day. Dolmage. (Seeley.)
The Romance of Modern Astronomy. Macpherson. (Seeley.)
The Vault of Heaven. Gregory. (Methuen.)
*The Elements of Descriptive Astronomy. Tancock. (Clarendon Press.)
*Astronomy. Hinks. (Williams & Norgate.)
*Time Measurement. Bolton. (Bell.)
Stars and How to Identify Them. Maunder. (Epworth Press.)
The Great Ball on Which We Live. Gibson. (Seeley.)

Physics

(See also list of "books of general scientific interest" given above.)

Some of Nature's Giant Forces. McDougall. (Pitman.)

Some of Nature's Wondrous Laws. McDougall. (Pitman.)

Nature's Mystic Movements. McDougall. (Pitman.)

The Wonders of Electricity. McDougall. (Pitman.)

Electrical Amusements and Experiments. Gibson. (Seeley.)

Our Good Slave Electricity. Gibson. (Seeley.)

Magnetism and Electricity. Staton. (Cassell.)

Electricity Book for Boys. Adam. (Harper.)

Electricity and Electrical Magic. Johnson. (Oxford Press.)

The Boy Electrician. Morgan. (Harrap.)

The Romance of Modern Electricity. Gibson. (Seeley.)

The Story of Electricity. Shearcroft. (Benn.)

Electricity of To-day. Gibson. (Seeley.)

Flying and Some of its Mysteries. Johnson. (Oxford Press.)

The Conquest of the Air. Berget. (Heinemann.)

Mechanics and Some of its Mysteries. Johnson. (Oxford Press.)

Mechanics. Thomson and Leslie. (Cassell.)
*Matter and Energy. Soddy. (Williams & Norgate.)
*Readable School Physics. Cochrane. (Bell.)
The Vacuum. Cochrane. (Bell.)
First Course in Physics. Millikan and Gale. (Ginn.)
Heat. Thompson and Leslie. (Cassell.)
Heat and Energy. Pye. (Oxford Press.)
Joule and the Study of Energy. Wood. (Bell.)
The Romance of Modern Photography. Gibson. (Seeley.)
Light Visible and Invisible. Thompson. (Macmillan.)
Waves and Ripples in Water, Air and Æther. Fleming. (S.P.C.K.)
The Mastery of Air. (Pitman.)
The Mastery of Earth. (Pitman.)
The Mastery of Fire. (Pitman.)
The Mastery of Water. (Pitman.)
The World of Sound. Bragg. (Bell.)
The Boy's Book of Wireless. Robinson. (Cassell.)
Wireless. Risdon. (Ward Lock.)
Wireless of To-day. Gibson. (Seeley.)
*Ether and Reality. Lodge. (Hodder & Stoughton.)
Concerning the Nature of Things. Bragg. (Bell.)

Chemistry

(See also list of "books of general scientific interest" given above.)

Everyday Chemistry. Robinson. (Methuen.)
Achievements of Chemical Science. Philip. (Macmillan.)
*Readable School Chemistry. Cochrane. (Bell.)
Chemistry of To-day. Bull. (Seeley).
*Chemistry in the Service of Man. Findlay. (Longmans.) Third Edition.
The Wonder Book of Chemistry. Fabre. (Fisher.)
Chemistry and its Mysteries. Gibson. (Seeley.)
The Romance of Modern Chemistry. Philip. (Seeley.)
*Chemistry of Familiar Things. Sadtler. (Lippincott.)
*Creative Chemistry. Slosson. (University of London Press Ltd.)
Chemistry. Thompson and Leslie. (Cassell.)
Chemistry and Chemical Magic. Johnson. (Oxford Press.)
Chemical History of a Candle. Faraday. (Dent.)
*History of Chemistry. Venable. (Harrap.)
*Short History of Chemistry. Stern. (Dent.)
Coal and What We Get from It. Meldola. (S.P.C.K.)
The Romance of Coal. Gibson. (Seeley.)
†Story of a Coal Mine. Berry. (Pitman.)

Peeps at Industries; Vegetable Oils. Browne. (Black.)

Biography

*Makers of Science. Hart. (Oxford Press.)

Masters of Space. (Morse, Thomson, Bell, Marconi, Carty.) Towers. (Harper.)

Pioneers of Progress (S.P.C.K.), including:

Men of Science.	Chapman.
Galileo.	Bryant.
Faraday.	Crowther.
Wallace.	Hogben.
Priestley.	Peacock.
Hooker.	Bower.
Herschel.	Macpherson.
Archimedes.	Heath.
Kepler.	Bryant.
Dalton.	Polley.
Copernicus.	Heath.

Pioneers of Science and Invention. Long. (Macmillan.)

APPENDIX II

FURTHER LIST OF BOOKS FOR THE SCIENCE LIBRARY

THE following list is given in order to bring the original list up-to-date at the time of printing the Third Edition.

BOOKS OF GENERAL SCIENTIFIC INTEREST

Modern Physics. Dull. (Harrap.)
Science. An Introductory Text-book. Holmyard. (Dent.)
Modern Science. A General Introduction Thomson. (Methuen.)
Introduction to Physical Science. Hart. (Oxford Press.)
Everyday Science. Parsons. 3 Parts. (Macmillan.)
Elementary Science for Girls. Royds. (Arnold.)
Why and How. Sankey and Royds. (McDougall.)
Science in the Home. Little. (Pitman.)
Elementary General Physical Science. Jamieson. (Melbourne: Brown, Prior & Co.)
Rambles in Science. (Blackie.)

The series includes:

Electricity as a Messenger.
Telephones and Gramophones.
Discoveries in Chemistry.
About Coal and Iron.

The Mysterious Ocean of Æther.
How We Harness Electricity.
Wireless.
How Photography came about.

A First Book of General Science. Simmons and Gale. (Macmillan.)

Everyday Science. Books I, II, III. Bean. (University of London Press.)

A First Book of General Science. Parts I, II. Gale. (University of London Press.)

Boy's Book of Popular Science. Ray. (Amalgamated Press.)

An Introduction to Science. Books I, II, III. Andrade & Huxley. (Blackwell.)

Science for Seniors. Books I, II, III, IV. Andrade & Huxley. (Blackwell.)

How and Why It Works. Boothroyd. (Schofield & Sims.)

Science in the Home. Little. (Pitman.)

Science in our Daily Life. Books I, II, III, IV. Marshall. (Wheaton.)

Elementary General Science. Books I, II, III. Hughes & Panton. (Blackie.)

Everyday Science. Parsons. (Macmillan.)

Wonder Book of Science. (Ward Lock.)

Boy's Own Book of Great Inventions. Darrow. (Macmillan.)

Introductory Science. Books I, II, III. Lauwerys. (Arnold.)

Nature Study

British Insect Life. Step. (Werner Laurie.)

Natural History. Animals. Jennison. (Black.)

Rural Science. Mason. (McDougall.)

Living Things for Lively Youngsters. (Rowland.) (Cassell.)
More Living Things for Lively Youngsters. Rowland. (Cassell.)

Biology, Hygiene and Physiology

The Conquest of Disease. Masters. (Lane.)
A First Book of Zoology. Burlend. (Macmillan.)
A First Book of Biology. Philips & Cox. (University of London Press.)
Science and Health. Little. (Pitman.)
Hygiene of the Home. Whipple. (Gregg.)

Geology

The World in the Past. Smith. (Warne.)
A First Book of Geology. Wilmore. (Macmillan.)

Astronomy

Astronomy. Dyson. (Dent.)

Physics

The Wonder Book of Electricity. (Ward Lock.)
Science and the Weather. Little. (Pitman.)
The Romance of Electricity. Randell. (Low.)
General Physics. Oldham & Langton. (University of London Press.)

Chemistry

Chemistry in Daily Life. Glasstone. (Methuen.)
The Marvels of Chemistry. McDougall. (Pitman.)
Chemistry. Lauwerys & Ellison. (University of London Press.)

Biography

Famous Chemists. The Men and their Work. Tilden. (Routledge.)

Makers of Science. Electricity and Magnetism. Turner. (Oxford Press.)

Some Famous Inventors. Tickner. (University of London Press.)